Nutrient Total Maximum Daily Load

For Alachua Sink,

Alachua County, Florida

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1. INTRODUCTION

1.1 Purpose of Report

This report represents the efforts to develop a nutrient TMDL for Alachua Sink. The sink, located in Central Florida near Gainesville (Figure 1), was verified as impaired by nutrients using the methodology in the Identification of Impaired Waters Rule (IWR, Rule 62-303, Florida Administrative Code), and was included on the verified list of impaired waters for the Ocklawaha River Group 1 Basin that was adopted by Secretarial Order on August 28, 2002.

Once a waterbody or waterbody segment has been verified as impaired and referenced in the Secretarial Order Adopting the Verified List of Impaired Waters, work on establishment of the Total Maximum Daily Load (TMDL) begins. The TMDL process establishes the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so that states can establish water quality based controls to reduce pollution from both point and nonpoint sources and restore and maintain the quality of their water resources (USEPA, 1991)

1.2 Identification of Water Body

Alachua Sink (WBID 2720A) is located on the northern edge of Paynes Prairie, south of the City of Gainesville, and approximately 2.5 miles east of the U.S. 441 highway. It consists of a small waterbody with a corresponding solution sink that recharges the Floridan Aquifer (Jones, Edmunds & Associates, Inc., 2003). Alachua Sink has a surface area of about 13.5 acres and a mean depth around 1 meter.

The sink is in a physiographic region of the state known as the Central Valley (McGrail et al., 1998), center latitude 29^0 36' 18" N. and longitude 82^0 18' 9" W. (Figure 1). The dominant, underlying geologic component of the Alachua Sink area is the Ocala limestone formation, with younger overlying terrace deposits of undifferentiated sediments, sand and clayey sand (Gottgens and Montague, 1988). The Ocala formation is a soft, porous limestone, interbedded with dense, hard limestone and dolomite (Clark et al., 1964). Sink formations have occurred in the area through subterranean erosion by groundwater solution of the limestone (McGrail et al., 1998).

The surrounding drainage basin for Alachua Sink is approximately 19,072 acres. There are two well-defined inflows into the sink - Sweetwater Branch and a culverted canal that connects Alachua Lake to Alachua Sink. Alachua Lake is the inundated portion of Paynes Prairie. Presumably, any runoff coming into Paynes Prairie that does not sink into the ground is incorporated into Alachua Lake and shunted to Alachua Sink during high water conditions. Major sources of flow to Paynes Prairie include Bivens Arm, Prairie Creek (which connects the prairie to Newnans Lake) and Camps Canal. Based on long-term USGS flow measurements (1942-1991), about 41% of the flow from Newnans lake goes south into Paynes Prairie, and the rest flows towards Orange Lake by way of Camps Canal (Gottgens and Montague, 1987). Aside from the sink feature itself, Alachua Sink has one surface water outlet located just north of the Alachua Lake culverted canal.

Historically the sink was used for recreation (ACLD, 2003). More recently, the sink has become dominated by a thriving alligator population that prohibits its use for this purpose. Increased urbanization of the nearby City of Gainesville has contributed pollutants through atmospheric deposition, stormwater runoff, and point source discharges. One domestic wastewater facility and one industrial wastewater facility are permitted to discharge effluent to Sweetwater Creek, which is connected to Alachua Sink via a canal. Septic tanks used in lesser developed parts of the sink's drainage have probably also contributed pollutants somewhat to the sink via tributaries to Paynes Prairie.

For assessment purposes, the Ocklawaha Basin has been divided into assessment polygons termed waterbody segments that are assigned unique **w**ater**b**ody **id**entification numbers (WBID). Additional information about the derivation and use of WBID numbers is provided in the "Documentation For The 2002 Update To The State Of Florida's 303(d) List" dated October 1, 2002, and GIS shapefiles of the waterbody segments can be obtained from the following website:
http://www.floridadep.org/water/watersheds/basin411/downloads.htm

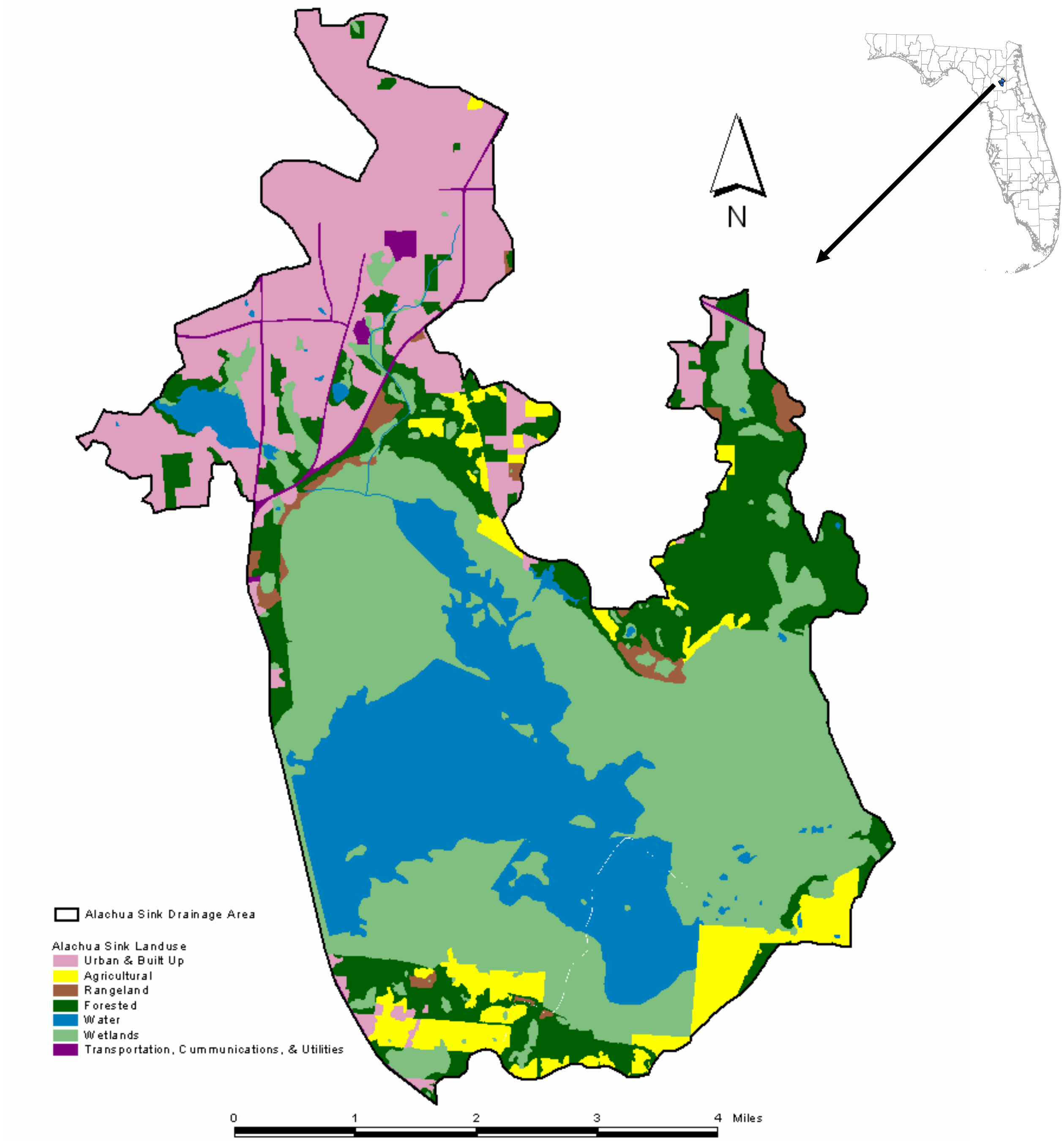

Figure 1. The general location and Land Uses of the Alachua Sink watershed in Florida

2. STATEMENT OF PROBLEM

Based on the water quality data provided by the St. Johns River Water Management District (SJRWMD), Alachua Sink was determined to have elevated nutrient and chlorophyll a (Chl a) values, with an average TSI for 2000 through 2002 of 78. For this period, the average annual total nitrogen (TN), total phosphorus (TP), and Chl a concentrations were 4.33 mg/L, 1.279 mg/L, and 40.8 µg/L, respectively. The mean color of the lake during this time period was calculated as 106 platinum-cobalt units.

3. DESCRIPTION OF APPLICABLE WATER QUALITY STANDARDS AND CRITERIA

Alachua Sink is classified as a Class III freshwater body, with a designated use of recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. The Class III water quality criterion applicable to the observed impairment is the narrative nutrient criterion [in no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna, Rule 62-302.530(48)(b), FAC]. Because the nutrient criterion is narrative only, a nutrient related target was needed to represent levels at which imbalance in flora or fauna are expected to occur. For this TMDL, the IWR threshold for impairment for lakes, which is based on a trophic state index (TSI), was used as the water quality target. Since the sink has a mean color greater than 40 platinum cobalt units, the IWR threshold for impairment is an annual mean TSI of 60, and the water quality target for the TMDL is therefore a TSI of less than or equal to 60, unless paleolimnological information indicates the natural annual average TSI of the lake was greater than 60. While the IWR threshold is based on the annual mean TSI, seasonal differences were considered in evaluating the sink. The TSI originally developed by R. E. Carlson (1977) was calculated based on Secchi depth, chlorophyll concentration, and total phosphorus concentration and was used to describe a lake's trophic state. Carlson's TSI was developed based on the assumption that the lakes were all phosphorus limited. In Florida, because the local geology produced a phosphorus rich soil, nitrogen can be the sole or co-limiting factor for phytoplankton population in some lakes. In addition, because of the existence of dark-water lakes in the state, using Secchi depth as an index to represent lake trophic state can produce misleading results. Therefore, the TSI was revised to be based on chlorophyll a, total nitrogen, and total phosphorus concentrations.

The Florida-specific TSI was determined based on the analysis of data from 313 Florida lakes. The index was adjusted so that a chlorophyll a concentration of 20 ug/L was equal to a TSI value of 60. A TSI of 60 was then set as the threshold for nutrient impairment for most lakes (for those with a color higher than 40 platinum cobalt units) because, generally, the phytoplankton may switch to communities dominated by blue-green algae at chlorophyll a levels above 20 ug/L. These blue-green algae are often an unfavorable food source to zooplankton and many other aquatic animals. Some blue-green algae may even produce toxins, which could be harmful to fish and other animals. In addition, excessive growth of phytoplankton and the subsequent death of these algae may consume large quantity of dissolve oxygen and result in anaerobic condition in lakes, which makes conditions in the impacted lake unfavorable for fish and other wildlife. All of these processes may negatively impact the health and balance of native fauna and flora.

Because of the amazing diversity and productivity of Florida lakes, some lakes have a natural background TSI that is different from 60. In recognition of this natural variation, the IWR allows for the use of a lower TSI (40) in very clear lakes, a higher TSI if paleolimnological data indicate the lake was naturally above 60, and the development of site-specific thresholds that better represent the levels at which nutrient impairment occurs. For this study, the Florida Department of Environmental Protection (DEP) used modeling to estimate the natural background TSI by setting land uses to natural or forested land, and then compared the TSI to the IWR thresholds. If the natural background TSI is higher than 60, then the natural background TSI would be used as the water quality target for the TMDL because it is unreasonable to abate the natural background condition. If the natural background TSI is lower than 60, then the IWR threshold (a TSI of 60) would be established as the target for TMDL development (since Alachua Sink has a mean color greater than 40 platinum cobalt units, the IWR threshold for impairment is 60).

4. ASSESSMENT OF SOURCES

4.1 Types of Sources

An important part of the TMDL analysis is the identification of source categories, source subcategories, or individual sources of nutrients in the Alachua Sink watershed and the amount of pollutant loading contributed by each of these sources. Sources are broadly classified as either "point sources" or "nonpoint sources." Historically, the term point sources has meant discharges to surface waters that typically have a continuous flow via a discernable, confined, and discrete conveyance, such as a pipe. Domestic and industrial wastewater treatment facilities (WWTFs) are examples of traditional point sources. In contrast, the term "nonpoint sources" was used to describe intermittent, rainfall driven, diffuse sources of pollution associated with everyday human activities, including runoff from urban land uses, runoff from agriculture, runoff from silviculture, runoff from mining, discharges from failing septic systems, and atmospheric deposition.

However, the 1987 amendments to the Clean Water Act redefined certain nonpoint sources of pollution as point sources subject to regulation under EPA's National Pollutant Discharge Elimination Program (NPDES). These nonpoint sources included certain urban stormwater discharges, including those from local government master drainage systems, construction sites over five acres, and from a wide variety of industries (see Appendix A for background information about the State and Federal Stormwater Programs).

For the purposes of allocating pollutant load reductions (see Section 6) required by a TMDL, the term "point source" will be used to describe traditional point sources (such as domestic and industrial wastewater discharges) AND stormwater systems requiring an NPDES stormwater permit. However, the methodologies used to estimate nonpoint source loads do not distinguish between NPDES stormwater discharges and non-NPDES stormwater discharges, and as such, this section does not make any distinctions between the two.

As noted previously, the goal of the TMDL development for Alachua Sink is to identify the maximum TP and TN loadings to the sink that will maintain the annual average TSI of the lake at, or lower than, 60. Analyses of the current water quality condition of Alachua Sink indicate that the long-term annual average TN/TP ratio is less than 10, suggesting that the phytoplankton community of the lake is nitrogen limited. Therefore, TN is the focus of this study. The impact of changes in TP loading was also estimated to provide a complete view of the nutrient dynamics of the watershed.

While TMDL development is a very complex process, the process used for this TMDL can be divided into three main steps:

1) TN and TP loadings from various point and nonpoint sources of pollution to the sink were estimated using the Watershed Management Model (WMM).

2) Loading estimates from the WMM were entered into the Bathtub eutrophication model to establish the relationship between TN and TP loadings and in-sink TN, TP, and Chl a concentrations. The model results for in-sink TN, TP, and Chl a were used to calculate TSI-predicted (TSI-P) for several different loading scenarios discussed later.
3) The loadings to the sink were adjusted until the TSI-P calculated from the model was less than 60. The TN and TP loadings that resulted in a TSI below 60 constituted the nutrient TMDL for Alachua Sink.

4.2 Estimating TN and TP Loadings Using WMM

Breakdown of Sub-basins and Land uses

The majority of the surface water flowing into, or occurring in, Paynes Prairie drains through Alachua Sink. Alachua Sink receives surface water primarily from three sources, including Sweetwater Branch, Alachua Lake, and the watershed area directly connecting to Alachua Sink (AS) (Figure 2). Sweetwater Branch collects the surface runoff from the Sweetwater Branch

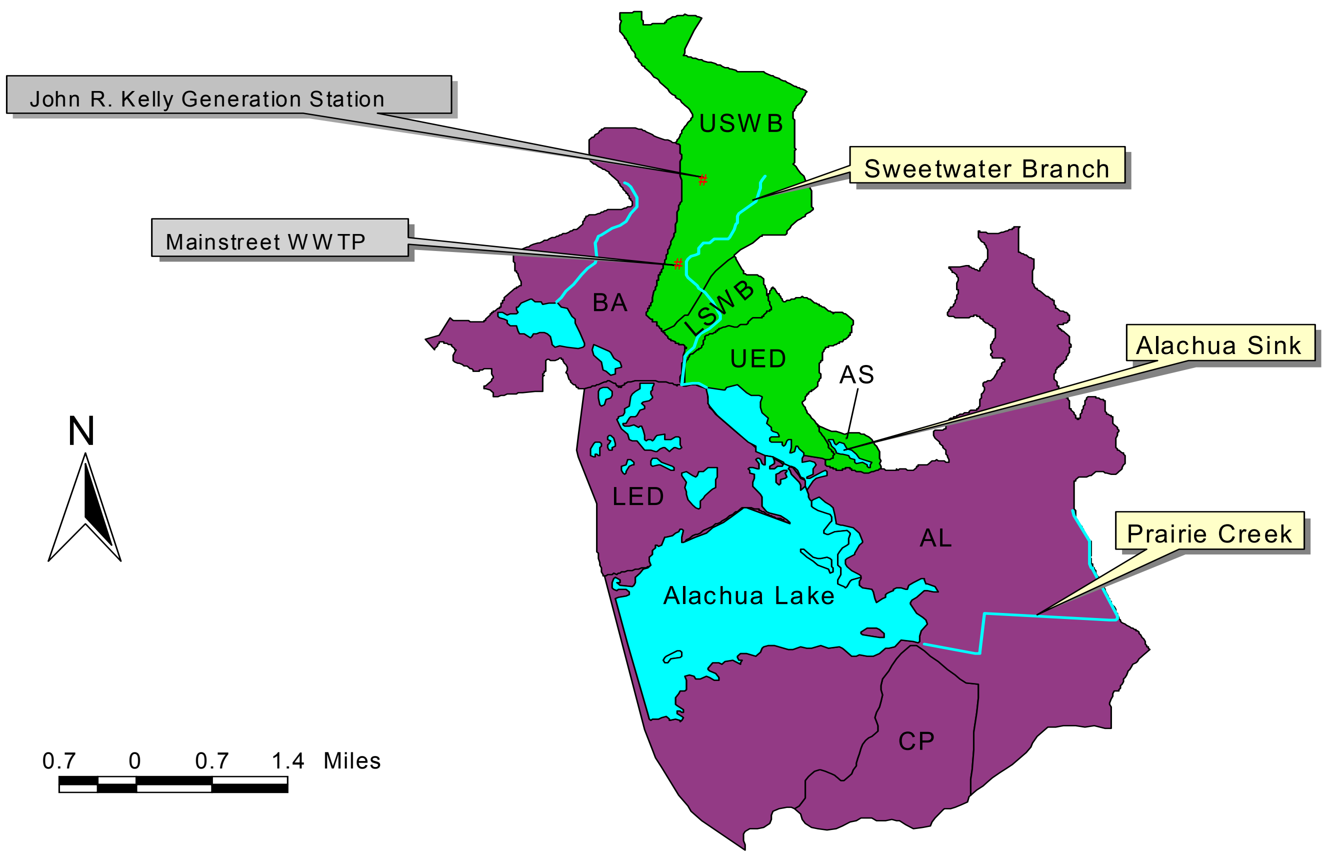

Figure 2. Delineation of the Paynes Prairie watershed. The area marked with green discharges into Sweetwater Branch. The area marked with purple discharges into Alachua Lake

watershed (SWB) and part of the Extension Ditch watershed (ED). Two point sources, including the Gainesville Regional Utilities' John R. Kelly Generating Station (Permit number FL0026646) and Main Street Domestic WasteWater Treatment Plant (Permit number FL0027251), discharge directly into Sweetwater Branch. Discharges from these facilities turns Sweetwater Branch from an intermittently flowing stream into an annual stream (Gottgens and Montague 1988).

Surface runoff from the Bivens Arm watershed (BA), part of the Extension Ditch watershed (ED), Alachua Lake watershed (AL), and Chacala Pond watershed (CP) all discharge into Alachua Lake. Portions of the water from Newnans Lake, located northeast of Paynes Prairie, is diverted into Alachua Lake through a control structure on Prairie Creek. A culverted structure controls the flow from Alachua Lake to Alachua Sink. All the water received by Alachua Sink is drained to the Florida aquifer through a sinkhole located in the northeast corner of Alachua Sink.

For the modeling purposes of this study, the Sweetwater Branch watershed (SWB) was further divided into two sub-basins: Upper Sweetwater Branch (USB) and Lower Sweetwater Branch (LSB). The Extension Ditch (ED) was also subdivided into two sub-basins including Upper Extension Ditch (UED) and Lower Extension Ditch (LED)(Figure 2).

Land use categories in each sub-basin were aggregated using the simplified level 1 codes. Acreage of each land use category discharging into Alachua Sink, through either Sweetwater Branch or Alachua Lake, is listed in Table 1.

Table 1. Classification of land use categories Alachua Sink

Code	Land Use	Through Sweetwater Branch	Through Alachua Lake
1000	Urban Open	686	705
	Low density resident	139	231
	Medium density resident	1741	530
	High density resident	54	284
2000	Agriculture	161	859
3000	Rangeland	55	188
8000	Transportation, communication, and utilities	94	139
4000	Forest/rural open	584	2233
5000/6000	Water/Wetland	692	7320
Total		**4207**	**12489**

<u>Potential Sources of TN and TP in the Alachua Sink Watershed</u>

TN and TP loadings into Alachua Sink from the following sources were estimated for the loading analysis:

- Loading through surface runoff
- Loading through atmospheric deposition directly into the sink
- Loading from point sources that discharge into Sweetwater Branch (John R. Kelly Generating Station and Main Street Wastewater Treatment Plant)
- Loading from septic tank leakage

Estimating Watershed TN and TP Loading

As noted previously, Watershed Management Model (WMM) was used to estimate TN and TP loading. Development of the WMM model was originally funded by DEP under contract to Camp Dresser and McKee (CDM). CDM further refined and developed the model to its present state. WMM is a watershed model designed to estimate annual or seasonal pollutant loadings from a given watershed and evaluate the effect of watershed management strategies on water quality (WMM User's Manual: 1998). While the strength of the model is its capability to characterize pollutant loadings from nonpoint sources, such as those through stormwater runoff, stream baseflow, and leakage of septic tanks, the model also handles point sources such as discharge from wastewater treatment facilities. Estimation of pollution load reduction due to partial or full-scale implementation of on-site or regional best management practices (BMP) is also part of the functions of the model. The fundamental assumption of the model is that the stormwater runoff from any given land use is in direct proportion to annual rainfall and is dictated by the portion of the land use category that is impervious and the runoff coefficients of both pervious and impervious area.

The governing equation for the model is:

(1) $R_L = [C_p + (C_I – C_p) IMP_L] * I$

Where:

R_L = total average annual surface runoff from land use L (in/yr);
IMP_L = fractional imperviousness of land use L;
I = long-term average annual precipitation (in/yr);
C_P = pervious area runoff coefficient; and
C_I = impervious area runoff coefficient.

The model estimates pollutant loadings based on nonpoint pollution loading factors (expressed as lbs/ac/yr) that vary by land use and the percent imperviousness associated with each land use. The pollution loading factor M_L is computed for each land use, L. by the following equation:

(2) $M_L = EMC_L * R_L * K$

Where:

M_L = loading factor for land use L (lbs/ac/yr);
EMC_L = event mean concentration of runoff from land use L (mg/L); EMC varies by land use and pollutant;
R_L = total average annual surface runoff from land use L computed from Equation (1) (in/yr); and
K = 0.2266, a unit conversion constant.

Data required for WMM application include:

- Area of all the land use categories and the area served by septic tanks
- Percent impervious area of each land use category
- EMC for each pollutant type and land use category
- Percent EMC of each pollutant type that is in suspended form
- Annual precipitation
- Point source flows and pollutant concentrations.

Calibration of WMM was conducted on both runoff quantity and quality. This was a two-step procedure since the water quality calibration is a function of the predicted runoff volumes. Calibration of water quantity is usually achieved through adjusting the pervious and impervious area runoff coefficients. Typical ranges of runoff coefficients are 0.05 – 0.30 for pervious area (WMM User's Manual: 1998) and 0.85 – 1.0 for impervious area (Linsley and Franziani, 1979). After the water quantity calibration, water quality was calibrated by adjusting the pollutant delivery ratio – the percent quantity of pollutant in the surface runoff that is eventually delivered to the destination waterbody. In this study, the range of the pollutant delivery ratio was estimated using the method developed by Roehl (1962) that correlates the delivery ratio to watershed area. The calibration results will be presented and discussed in Section 5.

4.3 Lake Modeling Using the Bathtub Model

<u>Bathtub eutrophication model</u>

The Bathtub eutrophication model is a suite of empirically derived steady state models developed by the U. S. Army Corps of Engineering (ACOE) Waterways Experimental Station. The primary function of these models is to estimate nutrient concentrations and algal biomass resulting from different patterns of nutrient loadings. The procedures for selection of the appropriate model for a particular lake are described in the Users Manual. The empirical prediction of lake eutrophication using this approach typically can be described as a two stage procedure using the following two categories of models (Walker 1999):

- *Nutrient balance model.* This type of model relates in-lake nutrient concentration to external nutrient loadings, morphometry, and hydrology.
- *Eutrophication response model.* This type of model describes relationships among eutrophication indicators within the lake, including nutrient levels, Chl <u>a</u>, transparency, and hypolimnetic oxygen depletion.

Figure 3 describes the concept scheme used by Bathtub to relate external loading of nutrients to the in-lake nutrient concentrations, and the physical, chemical, and biological response of the lake to the level of nutrients.

The *nutrient balance model* adopted by Bathtub assumes that the net accumulation of nutrients in a lake is the difference between nutrient loadings into the lake from various sources and the nutrients carried out through outflow and losses of nutrients through whatever decay process occurs inside the lake. The net accumulation in the lake is calculated using the following equation:

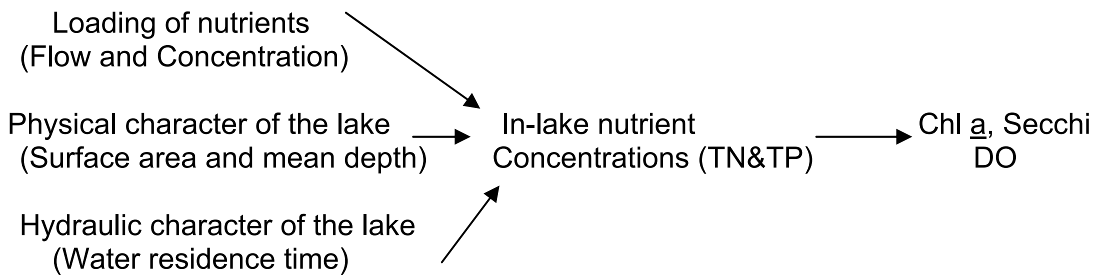

Figure 3. Bathtub concept scheme

(3) Net accumulation = Inflow – Outflow – Decay

Equation (3) is solved by assuming that the pollutant dynamics in the lake are at a steady state, i.e. the net accumulation of the pollutant in the lake equals zero.

In this study, "inflow" included TN and TP loadings through surface stormwater runoff from various land use categories, point sources, leakage of septic tanks, and atmosphere precipitation directly on the surface of Alachua Sink. To address nutrient decay within the sink, Bathtub provided several alternatives depending on the inorganic/organic nutrient partitioning coefficient and reaction kinetics. The major pathway of decay for TN and TP in the model is through sedimentation to the bottom of the sink.

Prediction of the *eutrophication response* by Bathtub also involves choosing one of several alternative models depending on whether the algal communities are limited by phosphorus or nitrogen, or co-limited by both nutrients. Scenarios that include algal communities limited by light intensity or controlled by the lake flushing rate are also included in the suit of models. In addition, the response of Chl a concentration to the in-lake nutrient level is characterized by two different kinetic processes: linear or exponential. The variety of models available in Bathtub allows the user to choose specific models based on the particular condition of the project lake. The specific Bathtub models used in this study are discussed in Section 5.

One feature offered by Bathtub is the "calibration factor." The empirical models implemented in Bathtub are mathematical generalizations about lake behavior. When applied to data from a particular lake, measured data may differ from predictions by a factor of two or more. Such differences reflect data limitations (measurement or estimation errors in the average inflow and outflow concentrations), unique features of the particular lake (Walker 1999), and unexpected processes inherent to the lake. The calibration factor offered by Bathtub provides model users with a method to calibrate the magnitude of lake response predicted by the empirical models. The model calibrated to current conditions (against measured data from the lake) can then be applied to predict changes in lake conditions likely to result from specific management scenarios under the condition that the calibration factor remains constant for all prediction scenarios.

Data Requirements for Running Bathtub

Data requirements for the Bathtub model include:

- Physical characteristics of the lake (surface area, mean depth, length, and mixed layer depth)
- Meteorological data (precipitation and evaporation retrieved from Climate Interactive Rapid Retrieval Users System of National Climate Data Center)
- Measured water quality data (TN, TP, and Chl a concentrations of the lake water, TN and TP concentrations in precipitation, etc.)
- Loading data (flow and TN and TP concentrations of the flow from various point and nonpoint sources of pollution)
- Coefficient of variance (CV) of all the measured data

Calculation of Trophic State Index (TSI)

TSI values were calculated using the procedures outlined in Florida's 1996 305(b) report:

$TSI = (CHLA_{TSI} + NUTR_{TSI})/2$

Where:

$CHLA_{TSI} = 16.8 + 14.4 \times LN (CHLA)]$

$TN_{TSI} = 56 + [19.8 \times LN(TN)]$

$TN2_{TSI} = 10 \times [5.96 + 2.15 \times LN(TN + 0.0001)]$

$TP_{TSI} = [18.6 \times LN(TP \times 1000)] -18.4$

$TP2_{TS} = 10 \times [2.36 \times LN(TP \times 1000) - 2.38]$

The procedure addresses limiting nutrient considerations by calculating $NUTR_{TSI}$:

If $TN/TP > 30$ then $NUTR_{TSI} = TP2_{TSI}$

If $TN/TP < 10$ then $NUTR_{TSI} = TN2_{TSI}$

If $10 < TN/TP < 30$ then $NUTR_{TSI} = (TP_{TSI} + TN_{TSI})/2$

Error and Variability Analysis

The distinction between "error" and "variability" is important. Error refers to a difference between a measured and a predicted mean value and is usually described as: the absolute value of [measurement – (prediction/measurement)]. Variability refers to spatial or temporal fluctuation in measurements around the mean. Spatial variability is not usually included in the variability analysis of empirical modeling efforts. Empirical modeling variability analysis usually concentrates on those changes caused by temporal fluctuation.

Variability is frequently described using the mean coefficient of variance (CV), which is defined as the standard error (SE) of the estimate expressed as a fraction of the predicted value (Walker 1999). In this study, model estimates were presented as mean $\pm$ 1SE whenever a CV could be determined.

When WMM was calibrated against measured water quantity and quality data, only error analysis was conducted. This was because the variability analysis of WMM required CVs for the EMC of TN and TP from different land use categories and the CV for the suspended fraction of TN and TP from different land use categories. Because these CVs were not available, the variability analysis was not conducted with WMM. Additionally, WMM does not have a place to input CVs of the measured annual precipitation and baseflow. WMM calibration was conducted using all the years for which data were available, and efforts were made to make sure that the error between model estimates and measured data were no greater than 10% for all the years.

Bathtub allows the input of the CV for both measured data and model predictions from WMM. Therefore, both error and variability analyses were conducted with Bathtub. To accomplish this, several years of measured data from the non-model variables (precipitation, lake volume, and evaporation) and the WMM predictions (TN, TP, and flow) were averaged and the mean values and CVs of these data were entered to Bathtub as input.

4.4 TMDL Scenario Development for Alachua Sink

Once WMM and Bathtub model calibrations were achieved (results discussed in the next section), the TMDL of the sink was developed through evaluating TSIs of the following scenarios:

A. TSI of the current condition
B. TSI after the directly connected impervious area (DCIA) and the event mean concentration of runoff from land uses (EMC) of all the human land use categories (urban open, low, medium, and high density residential, agriculture and rangeland, and transportation, communication, and utilities) were improved to the level of natural land (forest/ rural open), and the point source contribution was reduced to current annual average flow and given the concentration of the EMC for forest/rural open.

Scenario B was considered the natural background condition of the sink. The TN and TP loadings that result in a TSI of 60 would typically be considered as the TMDL of the sink. However, if the TSI of Scenario B was higher than 60, it would become the new target TSI threshold for the sink.

5. RESULTS

5.1 Current Trophic Status of Alachua Sink

Monthly TN, TP, and Chl a concentrations for Alachua Sink, from 2000 through 2002, were provided by St. Johns River Water Management District (SJRWMD, Site ID: ALACHCHAN). Quarterly mean values for TN, TP, and Chl a concentrations were calculated from the monthly data, and quarterly TSIs were calculated based on the quarterly mean values of TN, TP, and Chl a concentrations. Quarterly TN, TP, Chl a, and TSI values were then used to calculate annual mean values.

The seasonal trend of TN, TP, Chl a, and TSI were examined by calculating the long-term quarterly mean values based on the quarterly mean values of each year (2000 – 2002). The individual annual mean TN, TP, Chl a, and TSI values are listed in Table 2, and the long-term quarterly TN, TP, Chl a, and TSI results are listed in Table 3.

Table 2. Annual averages of TN, TP, Chl a, and TSI values of Alachua Sink from 2000 through 2002. Data represent the mean ± 1SE (n=4)

Year	TN (mg/L)	TP (mg/L)	Chl a (µg/L)	TSI
2000	4.51± 1.04	1.182 ± 0.243	46.3 ± 21.3	79 ± 2
2001	4.82 ± 0.81	1.353 ± 0.109	33.2 ± 15.3	77 ± 3
2002	3.65 ± 0.39	1.302 ± 0.229	43.0 ± 15.1	77 ± 3
Mean	**4.33 ± 0.35**	**1.279 ± 0.051**	**40.8 ± 3.9**	**78 ± 1**

As shown in Table 2, no significant inter-year difference was observed for TN, TP, Chl a, and TSI during the period from 2000 through 2002. The long-term annual average of TN, TP, and Chl a concentrations are 4.33 mg/L, 1.279 mg/L, and 40.8 μg/L, respectively. The long-term annual average TSI is 78. The long-term average TN/TP ratio for Alachua Sink is about 4, suggesting that the phytoplankton communities in this lake are nitrogen limited. Because the long-term annual average color of the lake is about 106, the IWR threshold for impairment the lake is an annual average TSI of 60. For the case of Alachua sink, the lake was verified as impaired based on annual average TSIs greater than 60, but it is important to note that the nutrient impairment is a long-term problem because the long-term average exceeds 60.

Table 3. Seasonal variation of TN, TP, Chl a, and TSI of Alachua Sink

Quarter	TN (mg/L)	TP (mg/L)	Chl a (μg/L)	TSI
1st quarter	5.06 ± 1.08	1.345 ± 0.335	26.6 ± 11.2	77 ± 2
2nd quarter	3.26 ± 0.38	0.915 ± 0.071	66.1 ± 12.4	81 ± 2
3rd quarter	3.75 ± 0.41	1.467 ± 0.055	50.4 ± 29.5	77 ± 5
4th quarter	5.25 ± 1.16	1.389 ± 0.210	20.3 ± 8.4	76 ± 2

Note: Data represent mean ±1SE. n equals to 3 years (2000 through 2002).

No statistically significant seasonal variation of TN, TP, Chl a, and TSI was observed during the period from 2000 through 2002 (Table 3).

5.2 Estimating TN and TP Sub-Basin Loadings Using WMM

As described in the previous section, Alachua Sink receives surface water from Sweetwater Branch and Alachua Lake. To estimate the nutrient load from Sweetwater Branch using WMM, the model was first set up through calibration against the flow data collected at a USGS flow gauging station located on the middle reach of the stream (Site Name: Sweetwater Branch at Gainesville, FL, Site ID: 02240988) (Figure 4). The Sweetwater Branch watershed was divided into upper and lower sub-basins during this study [Upper Sweetwater Branch (USB) and Lower Sweetwater Branch (LSB)] to take advantage of the flow data documented for this gauging station, and model calibration was conducted with the data for the Upper Sweetwater Branch (USB).

There were three full years of daily flow data available for the gauging station (1998 through 2000). However, the period during which water quality data were available for Bathtub calibration (2000 through 2002) did not overlap with the period that the flow data were available. Therefore, WMM calibration was conducted using the flow data of 1998, 1999, and 2000 and the calibrated model was then used to simulate the flow and TN and TP loadings in the period from 2000 through 2002 based on the rainfall data for these years. Because no full-year flow data were available in other areas of Paynes Prairie at the time this project was conducted, WMM calibration for the USB was applied to all the other sub-basins to simulate the surface runoff.

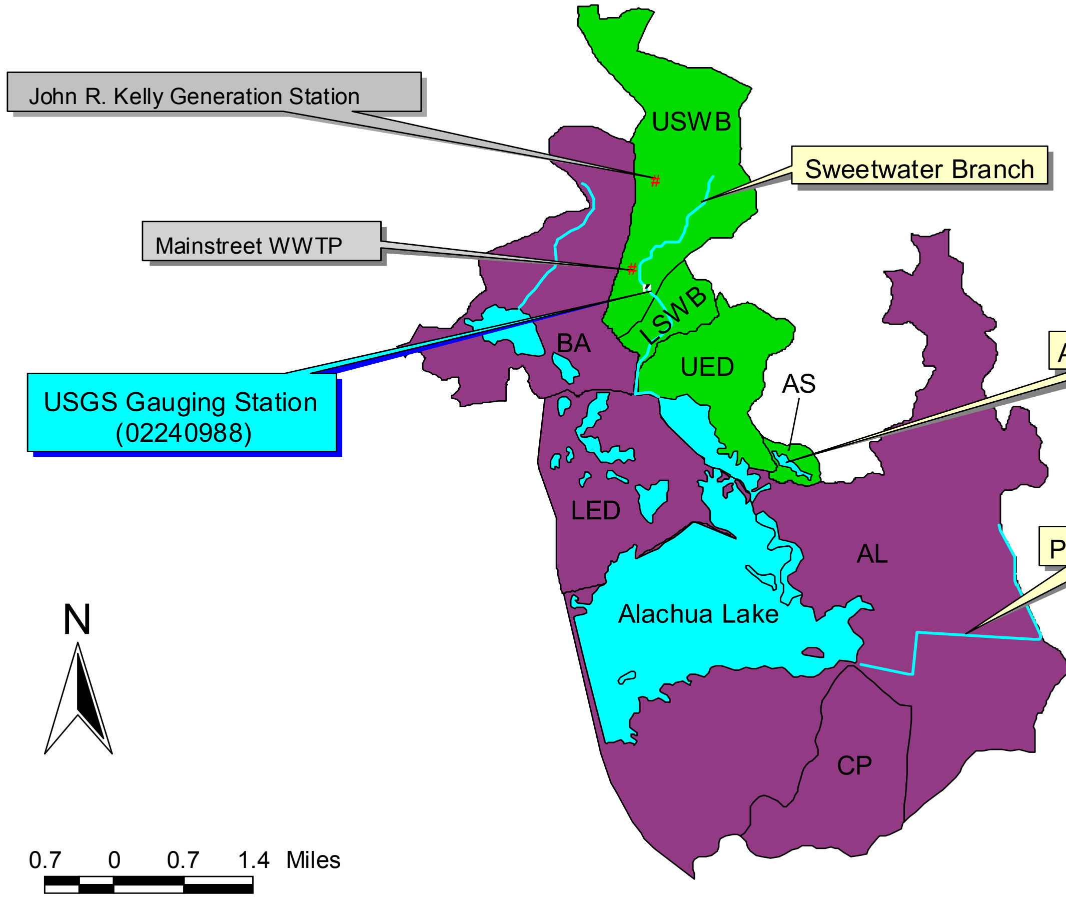

Figure 4. Location of the USGS flow gauging station (Site ID: 02240988) used for flow calibration

No water quality calibration was conducted for WMM because of the lack of reliable stream water quality data for the period from 2000 through 2002. Model input parameters for TN and TP loading estimation were based on the widely cited literature values (discussed in later section). Comparing the TN and TP loadings estimated using these model parameters with the TN and TP loading estimates obtained by a loading analysis conducted by Jones Edmunds & Associates, Inc. (JEA) (Alan Foley, personal communication, 2003) indicated a very close match, suggesting water quality parameters used in this study are reasonably accurate.

To estimate TN and TP loadings into Alachua Sink from Alachua Lake, the flow from Alachua Lake into Alachua Sink and TN and TP concentrations of Alachua Lake water were required. However, these data were not available for the period from 2000 through 2002. To solve this problem, WMM (calibrated using the above USGS gauging station) was applied to the BA, LED, AL, and CP watersheds to estimate the nonpoint flow and TN and TP loadings into Alachua Lake. TN, TP, and Chl a concentrations of Alachua Lake were then simulated using the Bathtub model.

Because of the control structure at the outlet of Alachua Lake and the low rainfall during the period from 2000 through 2002, it was inappropriate to assume that the amount of water discharged into Alachua Lake was the amount of water being conveyed to Alachua Sink. Therefore, the flow from Alachua Lake to Alachua Sink was obtained through calibrating the Bathtub model against the water quality data of Alachua Sink (2000 through 2002).

Data Required for Estimating TN and TP Loadings from Point and Nonpoint Sources Using WMM

To calibrate the flow estimates of WMM, the following data were used:

A. *Rain precipitation data* from the weather station located at the Gainesville Regional Airport (UCAN 3964, COOP 083326) were retrieved from the Climate Interactive Rapid Retrieval User System (CIRRUS) hosted by the Southeast Regional Climate Center. Annual average precipitation and seasonal variation are listed in Table 4.

Table 4. Annual precipitation at Gainesville Regional Airport

Year	Annual Precipitation	
	(in/year)	(m/year)
2000	34.39	0.87
2001	42.14	1.07
2002	55.33	1.41

B. *Daily flow data* for the gauging station mentioned in previous text, for the period from 1997 through 2001, were provided by SJRWMD. The data for 1997 were excluded from this study because only random measurements were available for each month from January to September, which was not sufficiently accurate for annual rainfall calculation. The daily flow data for the other years (1998 through 2001) were aggregated into annual flows and listed in Table 5.

Table 5. Annual stream flow of Sweetwater Branch at the USGS gauging station 02240988

Year	Annual Stream Flow	
	(acre-foot/year)	(hm^3/year)
1998	11238	13.9
1999	8973	11.1
2000	8029	9.9
2001	9767	12.1

C. *Areas of different land use categories* for each sub-basin were obtained by aggregating the GIS land use coverage based on the simplified level 1 code listed in Table 1. Acreage of each land use category for the watershed area that discharges into Alachua Sink through

Sweetwater Branch is listed in Table 6. The watershed area that discharges directly into Alachua Sink is also included in this table. The acreage of the watershed area that discharges into Alachua Sink via Alachua Lake is listed in Table 7. The percent area that each land use occupies in each sub-basin is listed in Table 8 and 9.

Table 6. Area of each land use category of the watershed that discharges into Alachua Sink through Sweetwater Branch

Land Use Type	Acreage			
	USB	LSB	UED	AS
Forest/Rural Open	136	94	292	62
Urban Open	608	60	18	0
Agriculture	8	9	144	1
Low Density Residential	25	106	2	6
Medium Density Residential	808	833	100	0
High Density Residential	54	0	0	0
Communication and Transportation	90	5	0	0
Rangeland	5	39	11	0
Water/Wetlands	87	56	498	52
Total	**1820**	**1202**	**1065**	**120**

Table 7. Area of each land use category of the watershed that discharges into Alachua Sink through Alachua Lake

Land Use Type	Acreage		
	BA	LED	AL + CP
Forest/Rural Open	226	148	1859
Urban Open	686	15	4
Agriculture	0	0	859
Low Density Residential	144	23	64
Medium Density Residential	420	0	111
High Density Residential	284	0	0
Communication and Transportation	88	22	29
Rangeland	22	43	124
Water/Wetlands	337	1587	5396
Total	**2206**	**1838**	**8445**

Table 8. Percent area of each land use category of the watershed that discharges into Alachua Sink through Sweetwater Branch

Land Use Type	Acreage			
	USB	LSB	UED	AS
Forest/Rural Open	7%	8%	27%	52%
Urban Open	33%	5%	2%	0%
Agriculture	0%	1%	14%	0%
Low Density Residential	1%	9%	0%	5%
Medium Density Residential	44%	69%	9%	0%
High Density Residential	3%	0%	0%	0%
Communication and Transportation	5%	0%	0%	0%
Rangeland	0%	3%	1%	0%
Water/Wetlands	5%	5%	47%	43%

Table 9. Percent area of each land use category of the watershed that discharges into Alachua Sink through Alachua Lake

Land Use Types	Acreage		
	BA	LED	AL + CP
Forest/Rural Open	10%	8%	22%
Urban Open	31%	1%	0%
Agriculture	0%	0%	10%
Low Density Residential	7%	1%	1%
Medium Density Residential	19%	0%	1%
High Density Residential	13%	0%	0%
Communication and Transportation	4%	1%	0%
Rangeland	1%	2%	1%
Water/Wetlands	15%	86%	64%

Based on Tables 8 and 9, areas occupied by urban and residential land uses (including low, medium, and high density residential areas) appear to be dominant land uses for the USB, LSB and BA sub-basins. The total areas of these land use types account for 82%, 83%, and 70% of the total watershed area in USB, LSB, and BA, respectively. In contrast, the AS, UED, LED, and AL + CP watersheds are dominated by natural land use types, including forest/rural open and water/wetland. The areas occupied by natural land use types represent 95%, 74%, 94%, and 86% of the total watershed area in AS, UED, LED, and AL + CP, respectively.

The watershed area that discharges to Alachua Sink through Sweetwater Branch appears to be influenced more by urban and residential land uses than the watershed area discharging through Alachua Lake. For the total 4,087-acre of watershed area that discharges into Sweetwater Branch, 2,621 acres are occupied by urban, open and residential land uses, which account for 64% of the total watershed area. About 1,750 acres out of 12,489 acres of the watershed that discharges into Alachua Lake is dominated by urban and residential land uses, which accounts for about 14% of total land uses.

D. *Percent impervious area* of each land use category is a very important parameter in estimating surface runoff using WMM. Nonpoint pollution monitoring studies throughout the U.S. over the past 15 years have shown that annual “per acre” discharges of urban stormwater pollution are positively related to the amount of imperviousness in the land use (WMM User’s Manual 1998). Ideally, *impervious area* is considered as the area that does not retain water and therefore, 100% of the precipitation falling on the impervious area should become surface runoff. In practice however, the runoff coefficient for impervious areas typically ranges between 95 to 100%. Impervious runoff coefficients lower than this range were observed in the literature, but usually this number should not be lower than 80%. For pervious areas, the runoff coefficient usually ranges between 10 to 20%. However, values lower than this range were also observed (WMM User’s Manual: 1998). In this study, impervious and pervious runoff coefficients were adjusted to fit model estimates to measured data in the process of WMM water quantity calibration.

   It should be noted that the impervious area percentages do not necessarily represent directly connected impervious area (DCIA). Using a single-family residence as an example, rain falls on rooftops, sidewalks, and driveways. The sum of these areas may represent 30% of the total lot. However, much of the rain that falls on the roof drains to the grass and infiltrates to the ground or runs off the property, and thus does not run directly to the street. For WMM modeling purpose, whenever the area of the watershed that contributes to the surface runoff was considered, DCIA was used in place of impervious area. Because local values were not available, DCIAs used in this study were collected from literature-published values or results from other studies (Table 10).

Table 10. Percent directly connected impervious area for different land use categories

Land Use Categories	DCIA	Reference
Forest/Rural Open	0.5%	WMM User’s Manual: 1998
Urban Open	15.4%	WMM User’s Manual: 1998
Agriculture	3.7%	Brown 1995
Low Density Residential	27.9%	WMM User’s Manual: 1998
Medium Density Residential	64.2%	WMM User’s Manual: 1998
High Density Residential	79.5%	WMM User’s Manual: 1998
Communication and Transportation	36.20%	Brown 1995
Rangeland	3.7%	CDM
Water/Wetlands	30%	Harper and Livingston 1999

E. Local *Event mean concentrations (EMC)* of TN and TP for different land use categories were not available and therefore were obtained from literature values (Table 11).

Table 11. Event mean concentration of TN and TP for different land use categories

Land Use Categories	TN (mg/L)	TP (mg/L)	Reference

Forest/Rural Open	1.25	0.053	Harper 1992
Urban Open	1.59	0.220	Harper 1992
Agriculture	2.58	0.465	Harper 1992
Low Density Residential	1.77	0.177	Harper 1992
Medium Density Residential	2.29	0.300	Harper 1992
High Density Residential	2.42	0.490	Harper 1992
Communication and Transportation	2.08	0.340	Harper 1992
Rangeland	1.25	0.053	Harper 1992
Water/Wetlands	1.60	0.189	Harper 1992

EMCs of TN and TP for most land use categories were cited from a review prepared by Harper (1992). EMCs for agriculture, low density residential, and water/wetlands were directly provided by the review. However, EMCs for urban open, medium density residential, high density residential, transportation and communication, and rangeland were not directly defined in Harper's review. Therefore, some extrapolations were made between the land use categories in this study and the land use categories defined by Harper's review. Basically, the urban open area was treated as the low-intensity commercial area in Harper's review. Medium density residential was treated as single family land use; high density residential was treated as multi-family land use; transportation and communication was treated mainly as highway; and rangeland was treated the same as general agriculture.

F. Not all of the TN and TP transported by stormwater are in the dissolved form. The *percentage of the total EMC represented by TN and TP attached to suspended particles* is allowed to be defined in WMM. Percent suspended TN and TP values were reported by Lasi (1999) for the Orange Lake watershed and were used in this study (Table 12).

Table 12. Percent TP and TN in suspended form for different land use categories

Land Use Categories	TP	TN
Forest/Rural Open	28%	6%
Urban Open	57%	44%
Agriculture	38%	20%
Low Density Residential	57%	44%
Medium Density Residential	57%	44%
High Density Residential	57%	44%
Communication and Transportation	57%	44%
Rangeland	38%	20%
Water/Wetlands	48%	77%

G. The s*ediment delivery ratio* determines how much TN and TP attaching to suspended particles will eventually be delivered to the destination waterbody. In this study, the range of the sediment delivery ratio was estimated using the correlation between delivery ratio and watershed area, developed by Roehl (1962), which is 30%.

H. To estimate the TN and TP loadings from *leakage of septic tanks*, WMM incorporates the concept of "septic tank failure loading rate", which defines the percent increase of TN and

TP loadings under septic tank leakage. The annual failure rate reported for the country is 3-5 percent. Pollutant loading rates reported in the WMM Users Manual assume 50 gallons per capita per day usage. The mid-range of loading rates for failing septic tanks in the Manual is 2.0 mg/L for TP (about a 160% to 250% increase) and for TN is 15.0 mg/L (about a 140% to 200% increase). To provide a Margin of Safety, this study adopted the high end of the range in the Users Manual, which were 30.0 mg/L for TN and 4.0 mg/L for TP.

I. Another value required by WMM to estimate the influence from leaking septic tanks on TN and TP loading is the "septic tank failure rate", which defines the frequency at which septic tanks may fail. Studies conducted on the water quality of the Ocklawaha River Basin found that the annual frequency of septic tank repairs was about 0.97% (Basin Status Report 2001). For average annual conditions, it is conservative to assume that septic tank system failures would be unnoticed or ignored for five years before repair or replacement occurred (WMM User Manual: 1998). Therefore, the septic tank failure rate used in this study was calculated by multiplying the repairing frequency (0.97%/year) by 5 (years). The result was about 5%.

J. Two point sources were identified in the Upper Sweetwater Branch sub-basin, including the Gainesville Regional Utilities John R. Kelly Generating Station (Permit number: FL0026646) and the Main Street Wastewater Treatment Plant (Permit number: FL0027251) (Figure 1). Monthly discharge flow and the TN and TP concentrations of the discharge from the Main Street Wastewater Treatment Plant from 2000 through 2002 were provided by Gainesville Regional Utilities and are provided in Table 13. Discharges from the John R. Kelly Generating Station are available from 2000 through 2002(Table 14). However, the permit does not require effluent monitoring for either TN or TP and the only available TN and TP concentrations of the discharge were from two bioassays conducted in 1991 and 2002. The TN and TP concentrations listed in Table 14 are the mean values from the TN and TP concentrations of the two bioassays.

Table 13. Daily discharge and TN and TP concentrations in the discharge from the Main Street Wastewater Treatment Plant

Year	Daily Discharge (MGD)	TN (mg/L)	TP (mg/L)
2000	5.35	5.01	1.641
2001	6.19	5.48	1.426
2002	6.05	4.39	0.500

Table 14. Daily discharge and TN and TP concentrations in the discharge from John R. Kelly Generating Station

Year	Daily Discharge (MGD)	TN (mg/L)	TP (mg/L)
2000	0.119	2.02	0.91
2001	0.092	2.02	0.91
2002	0.170	2.02	0.91

WMM Flow Calibration

Calibration of WMM on water quantity was primarily conducted through adjusting the runoff coefficients for pervious and impervious land use area to fit the estimates to the actual measurements. Table 15 lists observations, WMM predictions, errors, and pervious and impervious runoff coefficients for USB. From the table it can be seen that the model predicted the measured flows reasonably well.

Table 15. Results of WMM water quantity calibration for USB

Year	Measured Annual Flow (ac-ft/year)	Estimated Annual Glow (ac-ft/year)	Pervious Runoff Coefficient	Impervious Runoff Coefficient	Percent Error
1998	11238	**11324**	0.10	0.99	**0.8%**
1999	8973	**8821**	0.10	0.99	**1.7%**
2000	8029	**8485**	0.10	0.99	**5.7%**
2001	9767	**9929**	0.10	0.99	**1.7%**

WMM Flow Simulation

Keeping all of the model input parameters discussed above the same, the calibrated WMM model was then used to simulate surface runoff from all the other sub-basins in the period from 2000 through 2002, which is the period when water quality data for Alachua Sink were available. The predicted flow values for the watershed area that discharges to Alachua Sink through Sweetwater Branch (including the AS watershed) are listed in Table 16, and the flow predictions for the area discharging through Alachua Lake are listed in Table 17.

Table 16. Estimated annual flow (acre-foot/year) for the USB, LSB, UED, and AS sub-basins in the period from 2000 through 2002

Year	USB	LSB	UED	AS
2000	8485	1860	877	79
2001	9930	2280	1074	97
2002	10766	2993	1411	127

Table 17. Estimated annual flow (acre-foot/year) for the BA, LED, and AL + CP sub-basins in the period from 2000 through 2002

Year	BA	LED	AL + CP
2000	2610	1789	6921
2001	3199	2193	8480
2002	4200	2879	11134

WMM TN and TP Loadings Estimation

Using the EMCs, the percentage of nutrients in suspended form, sediment delivery ratio, and septic tank failure rate discussed in the previous sections, TN and TP loadings were estimated for all the sub-basins in the period from 2000 through 2002. The predicted TN and TP loadings for the watershed area that discharges to Alachua Sink through Sweetwater Branch (including the AS watershed) are listed in Table 18, and the loading predictions for the area discharging through Alachua Lake are listed in Table 19.

Table 18. Predicted TN and TP loadings (lbs/year) for the USB, LSB, UED, and AS sub-basins in the period from 2000 through 2002

Year	USB		LSB		UED		AS	
	TN	TP	TN	TP	TN	TP	TN	TP
2000	92933	28627	9130	1353	2712	398	194	24
2001	116950	29075	11187	1657	3324	488	238	29
2002	99175	12295	14689	2176	4364	640	312	38

Table 19. Predicted TN and TP loadings (lbs/year) for the BA, LED, and AL + CP sub-basins in the period from 2000 through 2002

Year	BA		LED		AC + CP	
	TN	TP	TN	TP	TN	TP
2000	11101	1898	3751	610	16760	2545
2001	13602	2326	4596	748	20537	3118
2002	17860	3054	6035	982	26966	4094

As shown in Table 18 and 19, the highest TN and TP loadings are from the USB. The TN and TP loadings to Alachua Sink through Sweetwater Branch are listed in Tables 20-21. Tables 20-A, B, and C list the TN loading from various point and nonpoint sources in 2000, 2001, and 2002, respectively. Tables 21-A, B, and C list the TP loading from various point and nonpoint sources. TN and TP loadings through Alachua Lake are listed in Tables 22-23. Tables 22-A, B, and C list the TN loading from various point and nonpoint sources in 2000, 2001, and 2002, respectively. Tables 23-A, B, and C list the TP loading from various point and nonpoint sources.

Table 20-A. Contribution of TN (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Sweetwater Branch in 2000

Land Use Type or Source	USB	LSB	UED	AS	Total	Percent Contribution
Forest/rural open	132	92	284	60	568	0.5%
Urban open	1238	122	37	0	1397	1.3%
Agriculture	18	22	332	1	373	0.4%
Low density residential	82	353	7	20	462	0.4%
Medium density residential	6702	6908	828	0	14438	13.8%
High density residential	571	0	0	0	571	0.5%

Transportation/communication	425	22	0	0	447	0.4%
Rangeland	6	43	12	0	61	0.1%
Water/wetland	182	117	1046	109	1454	1.4%
Septic tank	1471	1452	167	4	3094	2.9%
Main Street WWTP	81374	---	---	---	81374	77.5%
J. R. Kelly Generating Station	733	---	---	---	733	0.7%
Subtotal	**92933**	**9130**	**2712**	**194**	**104969**	**100.0%**

Table 20-B. Contribution of TN (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Sweetwater Branch in 2001

Land Use Type or Source	USB	LSB	UED	AS	Total	Percent Contribution
Forest/rural open	162	113	348	74	697	0.5%
Urban open	1517	149	46	0	1712	1.3%
Agriculture	22	26	406	2	456	0.3%
Low density residential	101	432	8	24	565	0.4%
Medium density residential	8213	8464	1014	0	17691	13.4%
High density residential	699	0	0	0	699	0.5%
Transportation/communication	521	27	0	0	548	0.4%
Rangeland	7	53	15	0	75	0.1%
Water/wetland	223	144	1281	133	1781	1.4%
Septic tank	1803	1779	205	5	3792	2.9%
Main Street WWTP	103118	----	----	----	103118	78.3%
J. R. Kelly Generating Station	566	----	----	----	566	0.4%
Subtotal	**116950**	**11187**	**3324**	**238**	**131699**	**100.0%**

Table 20-C. Contribution of TN (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Sweetwater Branch in 2002

Land Use Type or Source	USB	LSB	UED	AS	Total	Percent Contribution
Forest/rural open	212	148	457	97	914	0.8%
Urban open	1992	196	60	0	2248	1.9%
Agriculture	28	35	533	2	598	0.5%
Low density residential	132	567	11	32	742	0.6%
Medium density residential	10783	11114	1331	0	23228	19.6%
High density residential	918	0	0	0	918	0.8%
Transportation/communication	684	35	0	0	719	0.6%
Rangeland	9	69	20	0	98	0.1%
Water/wetland	292	189	1683	175	2339	2.0%
Septic tank	2367	2336	269	6	4978	4.2%
Main Street WWTP	80714	----	----	----	80714	68.1%
J. R. Kelly Generating Station	1042	----	----	----	1042	0.9%

Subtotal	99175	14689	4364	312	118540	100.0%

Table 21-A. Contribution of TP (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Sweetwater Branch in 2000

Land Use Type or Source	USB	LSB	UED	AS	Total	Percent Contribution
Forest/rural open	5	3	10	2	20	0.1%
Urban open	149	15	4	0	168	0.6%
Agriculture	3	3	51	0	57	0.2%
Low density residential	7	31	1	2	41	0.1%
Medium density residential	763	786	94	0	1643	5.4%
High density residential	100	0	0	0	100	0.3%
Transportation/communication	60	3	0	0	63	0.2%
Rangeland	0	2	0	0	2	0.0%
Water/wetland	31	20	180	19	250	0.8%
Septic tank	522	490	57	1	1070	3.5%
Main Street WWTP	26658	----	----	----	26658	87.7%
J. R. Kelly Generating Station	328	----	----	----	328	1.1%
Subtotal	**28627**	**1353**	**398**	**24**	**30402**	**100.0%**

Table 21-B. Contribution of TP (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Sweetwater Branch in 2001

Land Use Type or Source	USB	LSB	UED	AS	Total	Percent Contribution
Forest/rural open	6	4	12	3	25	0.1%
Urban open	182	18	5	0	205	0.7%
Agriculture	3	4	62	0	69	0.2%
Low density residential	9	38	1	2	50	0.2%
Medium density residential	934	963	115	0	2012	6.4%
High density residential	123	0	0	0	123	0.4%
Transportation/communication	74	4	0	0	78	0.2%
Rangeland	0	2	1	0	3	0.0%
Water/wetland	38	25	221	23	307	1.0%
Septic tank	640	600	70	1	1311	4.2%
Main Street WWTP	26812	----	----	----	26812	85.8%
J. R. Kelly Generating Station	253	----	----	----	253	0.8%
Subtotal	**29075**	**1657**	**488**	**29**	**31249**	**100.0%**

Table 21-C. Contribution of TP (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Sweetwater Branch in 2002

Land Use Type or Source	USB	LSB	UED	AS	Total	Percent Contribution
Forest/rural open	8	5	16	3	32	0.2%
Urban open	239	24	7	0	270	1.8%
Agriculture	4	5	82	0	91	0.6%
Low density residential	12	49	1	3	65	0.4%
Medium density residential	1227	1264	151	0	2642	17.4%
High density residential	161	0	0	0	161	1.1%
Transportation/communication	97	5	0	0	102	0.7%
Rangeland	0	3	1	0	4	0.0%
Water/wetland	50	33	290	30	403	2.7%
Septic tank	840	788	91	2	1721	11.4%
Main Street WWTP	9189	----	----	----	9189	60.7%
J. R. Kelly Generating Station	467	----	----	----	467	3.1%
Subtotal	**12295**	**2176**	**640**	**38**	**15149**	**100.0%**

Table 22-A. Contribution of TN (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Alachua Lake in 2000

Land Use Type or Source	BA	LED	AC + CP	Total	Percent Contribution
Forest/rural open	220	144	1808	2172	6.9%
Urban open	1397	31	8	1436	4.5%
Agriculture	0	0	1981	1981	6.3%
Low density residential	477	76	213	766	2.4%
Medium density residential	3479	0	917	4396	13.9%
High density residential	2989	0	0	2989	9.5%
Transportation/communication	417	105	136	658	2.1%
Rangeland	24	48	138	210	0.7%
Water/wetland	708	3332	11331	15371	48.6%
Septic tank	1389	15	226	1630	5.2%
Subtotal	**11101**	**3751**	**16760**	**31612**	**100.0%**

Table 22-B. Contribution of TN (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Alachua Lake in 2001

Land Use Type or Source	BA	LED	AC + CP	Total	Percent Contribution
Forest/rural open	269	176	2216	2661	6.9%
Urban open	1712	37	10	1759	4.5%
Agriculture	0	0	2427	2427	6.3%
Low density residential	585	94	262	941	2.4%
Medium density residential	4263	0	1124	5387	13.9%

High density residential	3663	0	0	3663	9.5%
Transportation/communication	511	129	167	807	2.1%
Rangeland	29	59	170	258	0.7%
Water/wetland	868	4083	13885	18836	48.6%
Septic tank	1702	19	277	1998	5.2%
Subtotal	**13602**	**4596**	**20537**	**38735**	**100.0%**

Table 22-C. Contribution of TN (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Alachua Lake in 2002

Land Use Type or Source	BA	LED	AC + CP	Total	Percent Contribution
Forest/rural open	354	231	2909	3494	6.9%
Urban open	2248	49	13	2310	4.5%
Agriculture	0	0	3187	3187	6.3%
Low density residential	768	123	343	1234	2.4%
Medium density residential	5598	0	1476	7074	13.9%
High density residential	4809	0	0	4809	9.5%
Transportation/communication	671	169	219	1059	2.1%
Rangeland	39	77	223	339	0.7%
Water/wetland	1139	5361	18231	24731	48.6%
Septic tank	2235	25	364	2624	5.2%
Subtotal	**17860**	**6035**	**26966**	**50861**	**100.0%**

Table 23-A. Contribution of TP (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Alachua Lake in 2000

Land Use Type or Source	BA	LED	AC + CP	Total	Percent Contribution
Forest/rural open	8	5	65	78	1.5%
Urban open	168	4	1	173	3.4%
Agriculture	0	0	305	305	6.0%
Low density residential	41	7	19	67	1.3%
Medium density residential	396	0	104	500	9.9%
High density residential	526	0	0	526	10.4%
Transportation/communication	59	15	19	93	1.8%
Rangeland	1	2	5	8	0.2%
Water/wetland	122	574	1953	2649	52.4%
Septic tank	578	4	74	656	13.0%
Subtotal	**1898**	**610**	**2545**	**5053**	**100.0%**

Table 23-B. Contribution of TP (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Alachua Lake in 2001

Land Use Type or Source	BA	LED	AC + CP	Total	Percent Contribution
Forest/rural open	10	6	79	95	1.5%
Urban open	205	4	1	210	3.4%
Agriculture	0	0	373	373	6.0%
Low density residential	51	8	23	82	1.3%
Medium density residential	485	0	128	613	9.9%
High density residential	644	0	0	644	10.4%
Transportation/communication	73	18	24	115	1.9%
Rangeland	1	2	6	9	0.1%
Water/wetland	150	704	2393	3247	52.4%
Septic tank	708	5	90	803	13.0%
Subtotal	**2326**	**748**	**3118**	**6192**	**100.0%**

Table 23-C. Contribution of TP (lbs/year) from different sources in the watershed that discharged into Alachua Sink through Alachua Lake in 2002

Land Use Type or Source	BA	LED	AC + CP	Total	Percent Contribution
Forest/rural open	13	8	104	125	1.5%
Urban open	270	6	2	278	3.4%
Agriculture	0	0	490	490	6.0%
Low density residential	67	11	30	108	1.3%
Medium density residential	637	0	168	805	9.9%
High density residential	846	0	0	846	10.4%
Transportation/communication	95	24	31	150	1.8%
Rangeland	1	3	8	12	0.1%
Water/wetland	196	924	3142	4262	52.4%
Septic tank	930	6	119	1055	13.0%
Subtotal	**3054**	**982**	**4094**	**8130**	**100.0%**

During the three years from 2000 through 2002, the total TN loadings conveyed through Sweetwater Branch (including USB, LSB, UED, and AS sub-basins) averaged 118,403 lbs/year, (Tables 20-A, B, and C). Total TP loadings averaged 25,600 lbs/year for the same period (Tables 21-A, B and C).

Of the total TN and TP loadings carried through these sub-basins, TN and TP loadings from the Main Street Wastewater Treatment Plant are the dominant components throughout the period. For TN, the loadings contributed by the Main Street Wastewater Treatment Plant are 81,374, 103,188, and 80,714 lbs/year in 2000, 2001, and 2002, respectively, representing 77.5%, 78.3%, and 68.1% of the total TN loadings carried through Sweetwater Branch. Surface runoff from the watershed (including USB, LSB, UED, and AS) contributes 22,863, 28,015, and 36,784 lbs TN/year, which represents from 22%, 21%, and 31% of the total TN loading in 2000, 2001 and 2002. For TP, the loadings contributed by the Main Street Wastewater Treatment Plant are 26,658, 26,812, and 9,189 lbs/year in 2000, 2001, and 2002 respectively, representing 87.7%, 85.8%, and 60.7% of the total TP loadings carried through Sweetwater Branch in this period. Surface runoff from the watershed (including USB, LSB, UED, and AS) contributes between 3,414, 4,184, and 5,493 lbs TP/year, which represents about 11%, 13%, and 36% of the total TP loading.

Both TN and TP loadings from nonpoint sources from the Sweetwater Branch watershed predicted by this study are very close to the loading estimates from a study conducted by Jones Edmunds & Associates, Inc (JEA 1999 through 2001). The years of overlap between the studies are 2000 and 2001. In their study, the nonpoint source TN loading was about 21,966 lbs/year compared to 25,439 in this study (average of years 2000 and 2001) and nonpoint source TP loading was about 3,614 lbs/year compared to 3,799 lbs/year in this study (average of years 2000 and 2001).

TN and TP loadings from the other point source – John R. Kelly Generating Station, are relatively insignificant and represent less than 1% of the total TN and TP loadings carried through Sweetwater Branch in the period of this study.

Among the nonpoint sources that discharge into Sweetwater Branch, urban and residential land uses appear to dominate the percent contribution of TN and TP loadings (Tables 20 to Table 21). These results indicated that the TN and TP loading in Sweetwater Branch is highly influenced by human activities.

No point sources were identified in the watershed area that discharged into Alachua Lake (BA, LED, and AC + CP). Although TN and TP loadings from the Bivans Arm watershed (BA) appear to be dominated by urban and residential land uses, the majority of the TN and TP loadings for the entire watershed area originate from natural lands, including forest/rural open and water/wetland area. Among the total loading from the watershed (including BA, LED, and AC + CP), about 55.5% of the TN and 53.9% of the TP come from forest/rural open and water/wetland land uses during the period covered by this study.

The majority of the TN and TP loading contributed by the human land use types comes from urban and residential land uses. This is mainly caused by the high percentage of land area occupied by urban and residential land uses in the Bivans Arm watershed (Table 22 through 23).

Atmospheric Loading of TN and TP into Alachua Sink and Alachua Lake

One source of TN and TP loading to Alachua Sink and Alachua Lake that was not considered by WMM was the TN and TP falling directly onto the surface of these waterbodies. In this study, atmospheric loading of TN and TP was calculated by multiplying the amount of precipitation directly falling onto the lake surface (calculated by multiplying the annual precipitation by the surface area of the lake) by the TN and TP concentration of the rainfall. Because no data for the TN and TP concentration of rainfall was available for the project area, published values were used in this study, which were 0.1 mg/L and 0.05 mg/L for TN and TP, respectively (Stites, et al 2001). Calculated annual TN and TP loadings from atmospheric loading are tabulated in Table 24.

Table 24. Atmospheric loading of TN and TP (lbs/year) into Alachua Lake and Alachua Sink

Year	Into Alachua Sink		Into Alachua Lake	
	TN	TP	TN	TP
2000	2	5	816	1632
2001	3	6	1143	2287
2002	4	8	1931	3861

<u>Simulated TN, TP, and Chl a Concentrations in Alachua Lake Using the Bathtub Model</u>

Another source of TN and TP loadings into Alachua Sink is the loadings from Alachua Lake. Because no flow and water quality data were available for the period from 2000 through 2001, annual average TN, TP, and Chl <u>a</u> concentrations of the sink were simulated using the Bathtub model.

<u>Data Required for the Simulation of TN, TP, and Chl a Concentrations in Alachua Lake</u>

The following data are required to simulate the TN, TP, and Chl <u>a</u> concentrations of Alachua Lake:

1. Physical characteristics of the lake (annual average surface area, mean depth, and mixed layer depth)
2. Meteorological data (annual average precipitation and evaporation)
3. Loading data (annual average flow and TN and TP concentrations of the flow from various land use types of the watershed).

All the data used for the Bathtub simulation are the mean values of annual averages taken over the period 2000 through 2002.

Data used for the model simulation are listed in Tables 25 through 27.

Table 25. Physical characteristics of Alachua Lake

Year	Lake Surface Area (km^2)	Mean Depth (m)	Mixed Layer Depth (m)
2000	18.68	0.50	0.50
2001	21.37	0.46	0.46
2002	27.48	0.49	0.49
Mean	**22.51**	**0.48**	**0.48**
SE	**2.60**	**0.01**	**0.01**

It should be noted that the physical characteristics data listed in Table 25 for Alachua Lake are not measured results. No measured lake characteristic data were available for the period 2000 through 2002. The following procedure was used to calculate the surface area and the mean depth of Alachua Lake:

1. The annual average lake surface elevation of Alachua Lake and the annual precipitation of the surrounding area were retrieved from USGS Hydrosphere database for the period from 1947 through 1952.

2. A regression equation was calculated for the relationship between the annual precipitation and lake surface elevation
   Lake surface elevation = 0.039 * annual precipitation + 53.09
3. The lake surface elevations for 2000, 2001 and 2002 were calculated based on the above equation and the annual precipitation data listed in Table 26.
4. The lake surface area and lake volume for 2000, 2001, and 2002 were estimated using the lake characteristic curve developed by SJRWMD for Paynes Prairie (Robison 1997).
5. The mean depth of the lake was calculated by dividing the lake volume by the surface area of the lake.
6. Because Alachua Lake is shallow, the mixed layer depth was assumed to be equal to the mean depth of the lake.

Estimating lake physical characters using this procedure results in additional uncertainties because the regression equation developed using data from 1947 to 1952 data may not totally match the current situation of the lake. This type of uncertainty is usually addressed through setting up an implicit margin of safety for the final TMDL.

Table 26. Precipitation and evaporation (m/year)

Year	Precipitation	Evaporation
2000	0.87	1.66
2001	1.07	1.48
2002	1.41	1.48
Mean	**1.12**	**1.54**
SE	**0.2**	**0.1**

Table 27. Alachua Lake Flow, TN and TP concentrations of different sources

Land Use Type or Source	Flow			TN			TP		
	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
	(hm^3/yr)			(mg/L)			(mg/L)		
Forest/Rural Open	1.05	0.15	14%	1.19	0.00	0.00	0.04	0.00	0.00
Urban Open	0.76	0.11	14%	1.10	0.00	0.00	0.13	0.00	0.00
Agricultural	0.52	0.07	14%	2.23	0.00	0.00	0.34	0.00	0.00
Low density residential	0.36	0.05	14%	1.22	0.00	0.00	0.11	0.00	0.00
Medium density residential	1.61	0.22	14%	1.58	0.00	0.00	0.18	0.00	0.00
High density residential	1.04	0.14	14%	1.67	0.00	0.00	0.29	0.00	0.00
Transportation, Communications, and Utilities	0.27	0.04	14%	1.44	0.00	0.00	0.20	0.00	0.00
Rangeland	0.11	0.02	14%	1.08	0.00	0.00	0.04	0.00	0.00
Water/Wetlands	12.14	1.69	14%	0.73	0.00	0.00	0.13	0.00	0.00
Prairie Creek	6.00	5.98	100%	3.87	0.00	0.00	0.16	0.00	0.00

Notes:

a) Bathtub does not allow direct input of loading. Therefore, data presented here are flow and TN and TP concentrations of the flow.
b) Flows for each source presented are calculated by aggregating individual flows from all the watersheds (BA, LED, AC+CP) and then averaging throughout the period from 2000 through 2002.
c) TN and TP concentrations presented for each source were calculated by adding TN and TP loadings from the entire watershed (BA, LED, AC+CP), dividing the sum by the total flow over all the watersheds, and then averaging throughout the period from 2000 to 2002.
d) Based on a TMDL study conducted on Newnans Lake, Prairie Creek diverts about 41% of the outflow from Newnans Lake into Paynes Prairie (Gao and Gilbert 2003). The flow and TN and TP concentrations used for Prairie Creek were the average over the period from 2000 through 2002.

Simulation of TN, TP, and Chl a Concentrations in Alachua Lake

To simulate TN, TP, and Chl a concentrations in Alachua Lake, each source of TN and TP was designated as an independent tributary. Flow, TN and TP concentrations of the flow were defined for each tributary as listed in Table 27. The TN and TP loadings from leaking septic tanks are not defined in Table 27 because, in Bathtub, septic tank loading is characterized differently from other point and nonpoint sources. Instead of being defined by flow and the pollutant concentration of the flow, septic tank loading is defined by the flux of TN and TP into the lake, which are calculated by dividing the septic tank TN and TP loadings by the surface area of the lake. In this study, annual average septic tank loads to Alachua Lake are 2084 lbs/year for TN and 838 lbs/year for TP. The annual average surface area of Alachua Lake for the study period was 22.51 k^2. Utilizing appropriate conversion units and dividing the loading by the surface area yields an annual average flux of 0.11 $mg/m^2/day$ for TN and 0.05 $mg/m^2/day$ for TP.

Bathtub provides several alternative submodels for estimating the influence of sedimentation on the in-lake TN and TP concentrations. In this study, the settling velocity submodel was chosen for both TN and TP. This submodel assumes that the sedimentation of TN and TP is in first-order kinetics and should linearly correlate with in-lake TN and TP concentrations. The submodel also assumes that the sedimentation is influenced by the depth of the lake. The deeper the lake, the slower the sedimentation. This submodel fit the conditions for Alachua Lake because the lake is relatively shallow and large in surface area. Continued wind mixing prevents the lake from forming thermal stratification, which would otherwise prevent the particles from being re-suspended once settled to the bottom. Continued wind mixing through the entire water column also reduces the particle settling rate by continuously bringing the settled particles back into the water column. These processes produce a relatively low settling rate in Alachua Lake.
Other sedimentation submodels provided by Bathtub assume second-order kinetics, which fit reasonably well with lakes that form thermal stratification during the summer. However, these models would overestimate the sedimentation of Alachua Lake, and in turn cause under-estimation of in-lake TN and TP concentrations.

The simulated concentrations of TN and TP concentrations for Alachua Lake are 1.191 mg/L and 0.141 mg/L respectively. Based on Bathtub-simulated TN and TP concentrations of Alachua Lake, the in-lake TN/TP ratio is less than 10, suggesting that the phytoplankton community of the lake is nitrogen limited. Bathtub does not provide any eutrophication response model that handles nitrogen limitation. Therefore, a Chl a-nitrogen regression curve, developed by Huber, et al. (1983) for Florida Lakes with TN/TP ratios of less than 10, was used to estimate the Chl a concentration. The regression equation is as the following:

$$\ln(\text{Chl } \underline{a}) = 2.97 + 1.49 * \ln(\text{TN})$$

Where, Chl a is the chlorophyll *a* concentration and TN is the total nitrogen concentration.

Simulated TN, TP, and Chl a concentrations based on the above-discussed model parameters and variables are listed in Table 28.

Table 28. Simulated TN, TP, and Chl a concentrations for Alachua Lake

Variable	Value
TP (mg/L)	0.141
TN (mg/L)	1.191
Chl a (µg/L)	25.3

5.3 Establishing the Relationship Between TN and TP Loading and In-lake TN, TP, and Chl a Concentrations of Alachua Sink

Data Required for Calibrating the Bathtub Eutrophication Model

The relationship between TN and TP loading and the in-lake TN and TP concentrations in Alachua Sink was established through fitting the Bathtub model predictions for the sink with the measured TN and TP concentrations of the sink. To calibrate the model, the following data were required:

1. Physical characteristics of the sink (surface area, mean depth, and mixed layer depth)
2. Meteorological data (precipitation and evaporation)
3. Measured water quality data (TN, TP, and Chl a concentrations of the sink water)
4. Loading data (flow and TN and TP concentrations of the flow from various point and nonpoint sources).

All of the data used for the Bathtub calibration were the mean annual averages over the period from 2000 through 2002. Data required for model calibration are listed in Tables 29 through 32.

Table 29. Physical characteristics of Alachua Sink

Year	Lake Surface Area (km^2)	Mean Depth (m)	Mixed Layer Depth (m)
2000	0.05	1.12	1.12
2001	0.05	1.12	1.12
2002	0.05	1.12	1.12
Mean	**0.05**	**1.12**	**1.12**
SE	**0.00**	**0.00**	**0.00**

The surface area and volume of Alachua Sink (Table 29) were determined based on the water depth at the time water quality data were collected (2000 through 2002, Site ID: ALACHCHAN) and the bathymetry of the sink characterized by Gainesville Regional Utilities (Figure 5). Mean depth of Alachua Sink was calculated by dividing the sink volume by the surface area of the sink. Due to the shallowness of Alachua Sink, the mixed layer depth was assumed to equal to the mean depth of the sink.

Table 30. Precipitation and evaporation (m/year)

Year	Precipitation	Evaporation
2000	0.87	1.66
2001	1.07	1.48
2002	1.41	1.48
Mean	**1.12**	**1.54**
SE	**0.2**	**0.1**

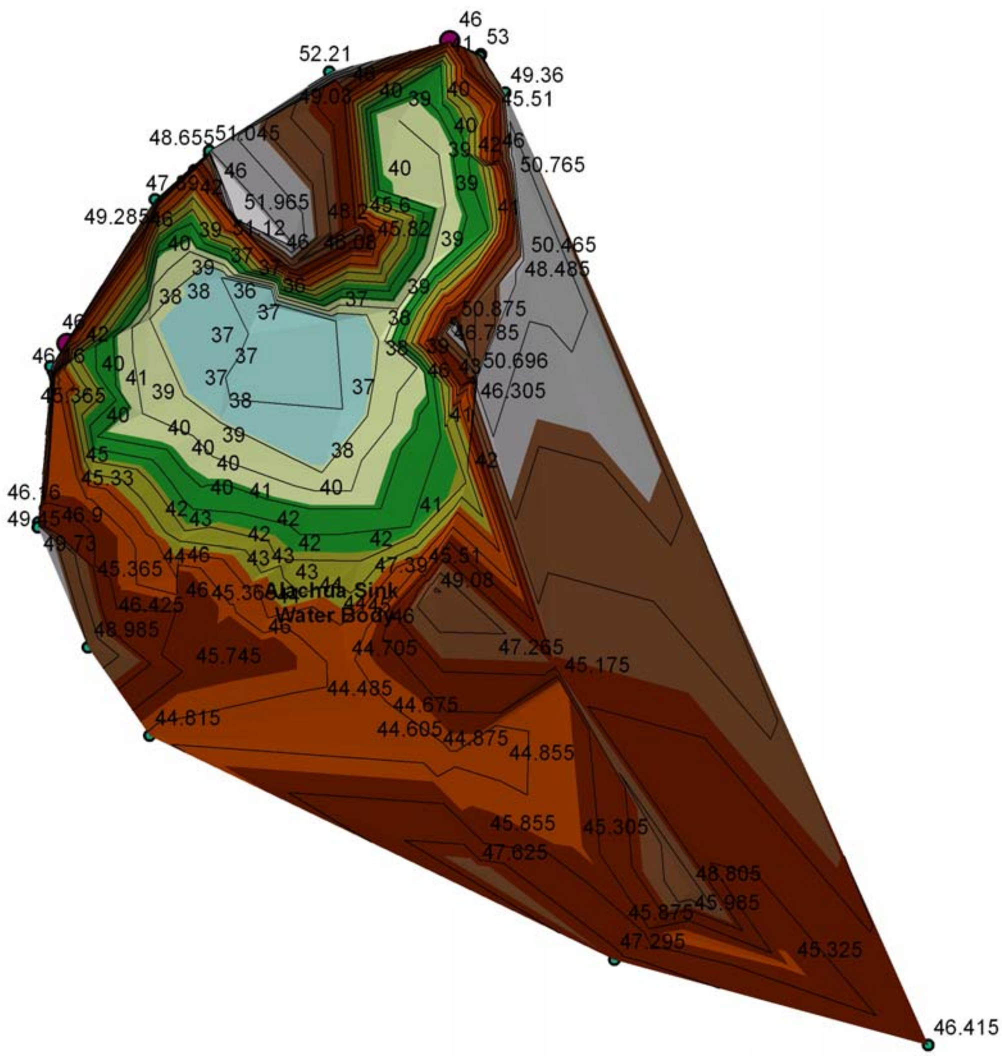

Figure 5. Bathymetry of Alachua Sink

Table 31. Measured TN, TP, and Chl a concentrations of Alachua Sink

Year	TN (mg/L)	TP (mg/L)	Chl a (µg/L)
2000	4.51	1.182	46.3
2001	4.82	1.353	33.2
2002	3.65	1.302	43.0
Mean	**4.33**	**1.279**	**40.8**
SE	**0.35**	**0.051**	**3.93**
CV	**8%**	**4%**	**10%**

Table 32. Alachua Sink Flow and TN and TP concentrations of different sources

Land Use Type or Source	Flow			TN			TP		
	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
	(hm^3/yr)			(mg/L)			(mg/L)		
Forest/Rural Open	**1.05**	**0.15**	**14%**	**1.19**	**0.00**	**0.00**	**0.04**	**0.00**	**0.00**
Urban Open	**0.76**	**0.11**	**14%**	**1.10**	**0.00**	**0.00**	**0.13**	**0.00**	**0.00**
Agricultural	**0.52**	**0.07**	**14%**	**2.23**	**0.00**	**0.00**	**0.34**	**0.00**	**0.00**
Low density residential	**0.36**	**0.05**	**14%**	**1.22**	**0.00**	**0.00**	**0.11**	**0.00**	**0.00**
Medium density residential	**1.61**	**0.22**	**14%**	**1.58**	**0.00**	**0.00**	**0.18**	**0.00**	**0.00**
High density residential	**1.04**	**0.14**	**14%**	**1.67**	**0.00**	**0.00**	**0.29**	**0.00**	**0.00**
Transportation, Communications, and Utilities	**0.27**	**0.04**	**14%**	**1.44**	**0.00**	**0.00**	**0.20**	**0.00**	**0.00**
Rangeland	**0.11**	**0.02**	**14%**	**1.08**	**0.00**	**0.00**	**0.04**	**0.00**	**0.00**
Water/Wetlands	**12.14**	**1.69**	**14%**	**0.73**	**0.00**	**0.00**	**0.13**	**0.00**	**0.00**
Main Street WWTP	**8.10**	**0.36**	**4%**	**4.95**	**0.32**	**6%**	**0.35**	**29%**	**0.35**
J. R. Kelly Generating Station	**0.18**	**0.03**	**18%**	**2.01**	**0.00**	**0%**	**0.00**	**0%**	**0.00**
Alachua Lake	**			**1.191**	**---**	**---**	**0.14**	**---**	**---**

**: Because no flow data from Alachua Lake to Alachua Sink were available at the control structure between them, the flow from Alachua Lake to Alachua Sink was characterized through Bathtub calibration to fit the predicted TN and TP concentrations to the measured TN and TP concentrations of Alachua Sink.

Calibrating the Bathtub Eutrophication Model

To calibrate the model, each source of TN and TP was designated as an independent tributary. Flow and TN and TP concentrations of the flow were defined for each tributary as listed in Table 32. The septic tank TN and TP flux into Alachua Sink were calculated as previously described to be 91.79 $mg/m^2/day$ and 31.74 $mg/m^2/day$, respectively.

As it was discussed in the previous section for Alachua Lake Bathtub modeling, the settling velocity submodel was chosen to estimate the in-sink concentrations of TN and TP.

Calibration factors were applied to fit TN and TP predictions to the measured data. Two calibration methods are provided by Bathtub for phosphorus and nitrogen: Method 0 calibrates decay rates and Method 1 calibrates concentration. In the first case, the calibration factors are applied to estimated sedimentation rates in computing nutrient balances. In the second case, the factors are applied to estimated concentrations. In Method 0, it is assumed that the error is attributed primarily to the sedimentation model. In Method 1, the error source is unspecified (some combination of input error and sedimentation model error). The latter may be used when predicted nutrient profiles are insensitive to errors in predicted sedimentation rate because the mass balance is dominated by inflow and outflow terms (low hydraulic residence times) (Walker 1999). In this study, Method 1 was adopted to calibrate the concentration. Typical calibration factors for TN and TP recommended by the Bathtub user's manual are 0.5 – 2.0 for TP and 0.33 – 3 for TN. In this study, 1.8 and 1.3 were used for calibrating TP and TN, respectively. Results of model calibration are shown in Table 33.

Table 33. Bathtub calibration results

Constituent	Measured		Estimated		Percent Error
	Mean	CV	Mean	CV	
TP (mg/l)	1.279	0.09	1.242	0.51	3%
TN (mg/l)	4.333	0.05	4.128	0.56	5%

As noted previously, flow from Alachua Lake to Alachua Sink was estimated during the Bathtub calibration. The calibrated flow during the period from 2000 through 2002 is 1 hm^3/year (about 810 ac-ft/year).

Chl a concentration could not be estimated by the Bathtub model because all of the eutrophication response submodel options provided with Bathtub assume a long enough water residence time for the phytoplankton biomass to respond to the change in TN and TP concentration. This assumption allows the use of characteristic regression curves between Chl a concentration and TN and TP concentrations. Considering that the volume of Alachua Sink was only about 48.5 ac-ft during the period from 2000 through 2002, and the average annual flow from Sweetwater Branch alone (not including the flow from Alachua Lake) into Alachua Sink during the same period was about 13326 ac-ft/year, the residence time in the sink is about 1.3 days. This time span would not allow phytoplankton biomass to increase to the extent that all the available nutrient in the water is fully used (most empirical relationships between Chl a and nutrient concentration were built based on the ANNUAL Chl a concentration and ANNUAL nutrient concentrations). Therefore, an empirical model was not used in this study. Instead, Chl a concentrations in Alachua Sink were estimated using the follow equation:

$$dA/dt * V = Q_{in} * A_{in} + kA*V - Q_{out} * A \quad (1)$$

where,

da/dt is the change rate of Chl a in Alachua Sink
V is the volume of Alachua Sink
Q_{in} is the inlet flow
A_{in} is the inlet Chl a concentration
K is the intrinsic growth rate of phytoplankton, which is usually considered about 0.5/day under natural conditions (Chapra, 1997)

A is the Chl a concentration of Alachua Sink
Q_{out} is the outlet flow

Assume that Alachua Sink is at a steady state:

$da/dt = 0$

Therefore:

$$0 = Q_{in} * A_{in} + k*A*V - Q_{out} * A \quad (2)$$

Re-arranging equation (2),

$$(Q_{out} - k*V) * A = Q_{in} * A_{in} \quad (3)$$

and

$$A = Q_{in} * A_{in} / (Q_{out} - k*V) \quad (4)$$

Assuming $Q_{in} = Q_{out}$ (i.e. the volume of Alachua Sink did not change during the study period) equation (4) can be converted to:

$$A = A_{in} / (1 - k * T) \quad (5)$$

Where, T is the water residence time of Alachua Lake during the period from 2000 through 2002.

In this study, A_{in} was calculated as the mean Chl a concentration of Sweetwater Branch and Alachua Lake weighted over the flow from these two sources. Table 34 lists the mean value of the measured Chl a concentration for Sweetwater Branch based on data provided by the SJRWMD. The mean flow of Sweetwater Branch and the Chl a concentration of Alachua Lake were predicted using the previously discussed Chl a-TN regression equation and the flow from Alachua Lake to Alachua Sink was characterized during the Bathtub calibration.

Table 34. Annual average flow and Chl a concentration in Sweetwater Branch and Alachua Lake in the period from 2000 through 2002

Parameter	Sweetwater Branch	Alachua Lake
Flow (ac-ft)	13226	810
Average annual Chl a (µg/L)	0.51	25.3

The A_{in} calculated based on the data in Table 34 is 1.92 µg/L.

Although the water residence time for Alachua Sink was calculated as 1.3 days, the inlet from Alachua Lake to Alachua Sink and the outlet from Alachua Sink to the primary sink feature are so close to each other that complete mixing of Alachua Sink by the inlet water may not happen regularly. This was in fact demonstrated by a study on the spatial distribution of Chl a concentration across Alachua Sink conducted by Jones Edmunds & Associates, Inc (JEA, 2003), which showed that Chl a concentration at the sampling site farthest away from the inlet could be higher than the Chl a concentration right at the inlet. This indicates that T, which is the actual water residence time experienced by phytoplankton communities in Alachua Sink, could be longer than 1.3 days because of the existence of the non-mixed area. Because the actual T of the phytoplankton community could not be calculated directly, it was adjusted to make the Chl a concentration predicted by equation (5) equal to the measured Chl a concentration in the period from 2000 through 2002. By assuming that the phytoplankton intrinsic growth rate is 0.5/days, the estimated water residence time based on an annual average Chl a concentration of 40.8 µg/L for Alachua Sink (Table 2) is about 1.9 days. Based on this result, Equation (5) is given as:

$$A = A_{in} / (1 - k * T) = A_{in} / (1 - 0.5 * 1.9) = 20 * A_{in} \quad (6)$$

TSI from Bathtub Predictions vs. TSI Based on Measured Data

The predicted TSI of Alachua Sink for the current condition was calculated using the Bathtub-estimated TN concentration and the Chl a concentration estimated using equation 6 (a TN/TP ratio less than 10 suggests that the sink is nitrogen limited). Table 35 lists the measured and predicted TN and Chl a concentrations and TSIs for the current condition of Alachua Sink.

Table 35. Alachua Sink TSI calculated using model-predicted and measured TN and Chl a concentrations in the period from 2000 through 2002

Constituent	Measured	Model Predicted
TN (mg/L)	4.33	4.13
Chl a (µg/L)	40.8	40.8
TSI	81	80

Based on the results listed in Table 35, the model-estimated TSI predicts the measured TSI reasonably well.

Evaluating the Natural Background TSI of Alachua Sink

The background TN and TP loading, without the loadings generated from the existing level of human activities, were estimated using the following procedures:

1. While the discharge volumes from both point sources (Main Street Wastewater Treatment Plant and J. R. Kelly Generating Station) were kept the same, their TN and TP concentrations were treated as equal to the TN and TP concentrations of surface runoff from forest/rural open land use types.
2. All the man-made land use categories (urban open, agricultural, low-density residential, medium density residential, high density residential, transportation and communication, and rangeland) in both the watershed areas that discharge into Sweetwater Branch and into Alachua Lake were evaluated as forest/rural open. All of the loadings from septic tanks were also removed.
3. TN and TP loadings through surface runoff into both Sweetwater Branch and Alachua Lake were then re-estimated using the calibrated WMM, the average annual precipitation of 43.95 inches/year (1.12 m/year), and the average annual evaporation of 60.52 inches/year (1.54 m/year) over the period from 2000 through 2002.
4. TN and TP concentrations from forest/rural open and water/wetland were calculated by dividing the total loadings by the total flow from the watershed (Tables 36 and 37).
5. TN, TP, and Chl a concentrations of the flow from Alachua Lake to Alachua Sink were re-estimated using the Bathtub model set up previously for Alachua Lake. The flow from Alachua Lake to Alachua Sink was kept at 1 hm^3/year (810 ac-ft/year) as it was characterized when the Bathtub model was calibrated for Alachua Sink.

Table 36. Flow and TN and TP concentrations of surface runoff into Sweetwater Branch

Land Use Type or Source	Flow (hm^3/year)	TN concentration (mg/L)	TP concentration (mg/L)
Forest/rural open	1.66	1.190	0.040

Water/wetland	1.15	0.730	0.130
Main Street WWTP	8.1	1.190	0.040
J. R. Kelly Generation	0.18	1.190	0.040

Table 37. Flow and TN and TP concentrations of surface runoff into Alachua Lake

Land Use Type or Source	Flow (hm^3/year)	TN concentration (ppb)	TP concentration (ppb)
Forest/rural open	2.44	1.190	0.040
Water/wetland	12.14	0.730	0.130

6. The flow and TN and TP concentrations of surface runoff from forest/rural open, water/wetland, and Alachua Lake into Alachua Sink were then entered into the calibrated Bathtub model to re-estimate the in-sink TN and TP concentrations.
7. Average Chl a concentrations of Sweetwater Branch and Alachua Lake (A_{in}) were calculated based on the CURRENT annual average Chl a concentration of Sweetwater Branch and changed Chl a concentration for Alachua Lake estimated using the Chl a-TN regression equation discussed in the previous section. The reason why the Chl a concentration in Sweetwater Branch was assumed unchanged even after the TN loading from the Sweetwater Branch watershed was reduced significantly was because the Chl a concentration of Sweetwater Branch does not appear to be determined by the nutrient concentration (recall that the Chl a concentrations in the branch are very low even though nutrient concentrations are relatively high).
8. The TSI was then calculated based on the predicted TN and Chl a concentrations. The background TSI value calculated based on background TN and Chl a concentrations is about 70, representing a 14% decrease from the current TSI of 81. This TSI was considered the natural background TSI of Alachua Sink and any further reduction of the TSI of the lake by additional reductions in the loadings was not considered. The re-modeled TN, TP, and Chl a concentrations of Alachua Lake are listed in Table 38. Background TN, TP, and Chl a concentration and TSI of Alachua Sink are listed in Table 39.

Table 38. Simulated natural background TN, TP, and Chl a concentrations for Alachua Lake

Variable	Value
TP (mg/L)	0.116
TN (mg/L)	1.11
Chl a (µg/L)	22.8

Table 39. Alachua Sink TN, TP, and Chl a concentrations and TSI after all the human land use categories were treated as forest/rural open, and loadings from point sources were totally removed

Variable	Value
TP (mg/l)	0.101
TN (mg/l)	1.504
Chl a (µg/l)	46.0

Mean TSI	**70**

As shown by comparing Table 38 and Table 39, TN and TP concentrations decreased 65% and 92% from 4.33 mg/L and 1.279 mg/L to 1.504 mg/L and 0.101 mg/L, respectively. However, Chl a increased 15% from 40 µg/L to 46 µg/L. The reason why the Chl a concentration increased while both TN and TP concentrations drastically decreased was because, in Alachua Sink, the Chl a concentration is not limited by the availability of nutrients. Instead, it is controlled by water residence time, which is too short for phytoplankton to grow to the full extent that the nutrient concentration would allow. When all of the human land use types in Sweetwater Branch were treated as forest/rural open land area, surface runoff in Sweetwater Branch decreased from 13,226 ac-ft to 8,987 ac-ft. Because the Chl a concentration in Sweetwater Branch is low (0.51 µg/L) and the Chl a concentration in Alachua Lake is high, decreasing the flow in Sweetwater Branch could cause A_{in} to increase. Assuming the same retention time in the Lake would increase the Chl a concentration. This could cause the Chl a concentration in Alachua Sink to increase.

Summary of TN and TP Loading for Current Condition and Background Condition

TN and TP loadings into Alachua Sink from point and nonpoint sources under current conditions and background conditions are summarized in Table 40.

Table 40. Alachua Sink TN and TP loadings (lbs/year) from point and nonpoint sources under current and background conditions

Sources	Current Condition		Background Condition	
	TP	TN	TP	TN
Watershed	2998	25234	476	6206
Septic Tanks	1367	3954	0	0
Precipitation	7	13	7	13
Main Street WWTP	21250	88393	714	21250
J. R. Kelly Generating Station	357	798	15	472
Alachua Lake	311	2626	254	2458
Total	**26290**	**121019**	**1466**	**30399**

6. DETERMINATION OF TMDL

The objective of a TMDL is to provide a basis for allocating acceptable loads among all of the known pollutant sources in a watershed so that appropriate control measures can be implemented and water quality standards achieved. A TMDL is expressed as the sum of all point source loads (Waste Load Allocations), nonpoint source loads (Load Allocations), and an appropriate margin of safety (MOS), which takes into account any uncertainty concerning the relationship between effluent limitations and water quality:

$$\mathbf{TMDL = \sum WLAs + \sum LAs + MOS}$$

As mentioned in Section 4.1, the WLA is broken out into separate subcategories for wastewater discharges and stormwater discharges regulated under the NPDES Program:

$$\textbf{TMDL} \cong \sum \textbf{WLAs}_{\textbf{wastewater}} + \sum \textbf{WLAs}_{\textbf{NPDES Stormwater}} + \sum \textbf{LAs} + \textbf{MOS}$$

It should be noted that the various components of the TMDL equation may not sum up to the value of the TMDL because a) the WLA for NPDES stormwater is typically based on the percent reduction needed for nonpoint sources and is accounted for within the LA, and b) TMDL components can be expressed in different terms [for example, the WLA for stormwater is typically expressed as a percent reduction and the WLA for wastewater is typically expressed as a mass per day].

WLAs for stormwater discharges are typically expressed as "percent reduction" because it is very difficult to quantify the loads from MS4s (given the numerous discharge points) and to distinguish loads from MS4s from other nonpoint sources (given the nature of stormwater transport). The permitting of stormwater discharges is also different than the permitting of most wastewater point sources. Because stormwater discharges cannot be centrally collected, monitored and treated, they are not subject to the same types of effluent limitations as wastewater facilities, and instead are required to meet a performance standard of providing treatment to the "maximum extent practical" through the implementation of Best Management Practices.

This approach is consistent with federal regulations [40 CFR § 130.2(I)], which state that TMDLs can be expressed in terms of mass per time (e.g. pounds per day), toxicity, or **other appropriate measure**. The nutrient TMDL for Alachua Sink (Table 41) is expressed in terms of pounds per year and/or percent reduction. Because TN is the limiting nutrient for Alachua Sink phytoplankton communities, the Alachua Sink TMDL is only developed for TN loadings (Table 41).

The TN and TP loadings from major sources to Alachua Sink during the period of this study were listed in Table 40. The total annual average loadings to the sink for the current condition are 12,1019 lbs/year for TN and 26,290 lbs/year for TP. To evaluate natural background, the impact of loadings from all human based nonpoint sources were removed by resetting the land uses to forest/open and all the loadings septic tanks were removed. The TN and TP concentrations of the discharges from the Main Street Wastewater Treatment Plant and the John R. Kelly Generating Station were decreased to the level of the surface runoff from forest/open land use type and the flows were set at the current annual averages. The loadings from this scenario became the natural background condition. The annual TN and TP loadings to the sink dropped to 30,399 lbs/year and 1,466 lbs/year, respectively. This represents a 75% reduction of TN and a 94% reduction of TP loadings. After this loading reduction is achieved, the TSI of the lake is predicted to decrease to about 70. Because 70 is the natural background condition of the sink, no further reduction in loading was considered necessary in this study. The allowable load allocation loadings are 30,399 lbs TN/year. This corresponds to a load reduction of 75% from the existing condition.

Table 41. TMDL Components

WBID	Parameter	WLA		LA (lbs/year)	MOS	TMDL (lbs/year)	Percent Reduction
		Wastewater (lbs/year)	NPDES Stormwater				
2720A	TN	21,722	75% reduction	8,677	Implicit	30,399	75

6.1 Load Allocation

The allowable LA is 8,677 lbs/year for TN. This corresponds to reductions from the existing loadings of 75 percent for TN. It should be noted that the LA includes loading from stormwater discharges regulated by the Department and the Water Management Districts that are not part of the NPDES Stormwater Program (see Appendix A).

6.2 WasteLoad Allocation

NPDES Stormwater Discharges

As noted in Sections 4 and 6.1, load from stormwater discharges permitted under the NPDES Stormwater Program are placed in the WLA, rather than the LA. This includes loads from municipal separate storm sewer systems (MS4). Based on the 2000 census, the Alachua Sink watershed includes areas that are covered by the MS4 Program, and the WLA for stormwater discharges is a 75 percent reduction of current loading from the MS4. It should be noted that any MS4 permittees will only be responsible for reducing the loads associated with stormwater outfalls for which it owns or otherwise has responsible control, and is not responsible for reducing other nonpoint source loads within its jurisdiction.

NPDES Wastewater Discharges

The Wasteload Allocation for the NPDES surface water discharges is 21,722 lbs/year.

The TMDL developed for Alachua Sink in this study was based on the only available water quality data measured in the period from 2000 through 2002. These are relatively dry years during which no water or a very limited amount of water was discharged into Alachua Sink from Alachua Lake. Therefore the TMDL developed in this study could be considered as developed under critical conditions. This might shed light on why the background TSI of Alachua Sink is relatively high. Because the surface runoff from the watershed was limited during these dry years, TN loading from point sources, especially the loading from the Main Street Wastewater Treatment Plant played a very important role in influencing the water quality of Alachua Sink. Among the total 121,019 lbs of TN discharged into Alachua Sink annually (Table 40), the Main Street Wastewater Treatment Plant contributes 88,393 lbs, which represents about 73% of the total TN loading into Alachua Sink. Decreasing the TN concentration of the discharge from this facility from the current 4.33 mg/L to 1.19 mg/L (level of the surface runoff from forest/rural open land type) could reduce the TSI from 81 to about 71 under this relatively dry condition. Changing the land use type could only influence about 1 unit of TSI. Even in the 30,399 lbs of

TN total annual load that results in the background condition, the TN load from the Main Street Wastewater Treatment Plant still amounts to 21,250 lbs/year, which accounts for about 69% of the total TN load into Alachua Sink, indicating the importance of this facility in controlling the water quality of Alachua Sink. However, the Department does not recommend removal of the discharge from the Main Street Wastewater Treatment Plant because it's discharge accounts for the majority of the flow in Sweetwater Branch between the discharge point and the canal leading to Alachua Sink, therefore it serves as a very important source of water for Alachua Sink. This is especially true during dry years when there is no water coming over the control structure from Alachua Lake into Alachua Sink.

6.3 Margin of Safety

The methodology used to determine this TMDL includes an implicit MOS because it relies on the natural background TSI as the target for the TMDL and does not account for the capacity of the natural system to assimilate nutrients without causing an imbalance in flora or fauna. Additional implicit margins of safety exist due to some of the assumptions made during the modeling process. Such assumptions include use of maximum septic tank loading rates and maximum rates of septic tank failure.

7. NEXT STEPS: IMPLEMENTATION PLAN DEVELOPMENT AND BEYOND

Following adoption of this TMDL by rule, the next step in the TMDL process is to develop an implementation plan for the TMDL, which will be a component of the Basin Management Action Plan for the Alachua Sink Basin. This document will be developed in cooperation with local stakeholders and will attempt to reach consensus on more detailed allocations and on how load reductions will be accomplished.

The Basin Management Action Plan (B-MAP) will include:

- Appropriate allocations among the affected parties.
- A description of the load reduction activities to be undertaken.
- Timetables for project implementation and completion.
- Funding mechanisms that may be utilized.
- Any applicable signed agreements.
- Local ordinances defining actions to be taken or prohibited.
- Local water quality standards, permits, or load limitation agreements.
- Monitoring and follow-up measures.

It should be noted that TMDL development and implementation is an iterative process, and this TMDL will be re-evaluated during the BMAP development process and subsequent Watershed Management cycles. The Department acknowledges the uncertainty associated with TMDL development and allocation, particularly in estimates of nonpoint source loads and allocations for NPDES stormwater discharges, and fully expects that it may be further refined or revised over time. If any changes in the estimate of the assimilative capacity AND/OR allocation between point and nonpoint sources are required, the rule adopting this TMDL will be revised, thereby providing a point of entry for interested parties.

SECTION 8. RECOMMENDATIONS

Because the background TSI of Alachua Lake was established based solely on the water quality data from dry years from 2000 through 2002 (the only available water quality data that allowed the model calibration in this study) during which no water or very limited amount of water was discharged from Alachua Lake to Alachua Sink, the influence of Alachua Lake on the water quality of Alachua Sink could not be quantitatively addressed in this study. Currently, a study on the water quality of Alachua Sink and influence from point and nonpoint sources on the water quality of Alachua Sink is being conducted by Jones Edmunds & Associates, Inc (JEA). This report recommends that this type of study should be conducted to establish the relationship between TN loading and TN and Chl a concentrations in Alachua Sink under long-term average rainfall condition before BMP implementation so that the TMDL for Alachua Sink can be revised to reflect normal rainfall conditions instead of only in dry years.

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Appendix A

In 1982, Florida became the first state in the country to implement statewide regulations to address the issue of nonpoint source pollution by requiring new development and redevelopment to treat stormwater before it is discharged. The Stormwater Rule, as authorized in Chapter 403, Florida Statutes (F.S.), was established as a technology-based program that relies upon the implementation of BMPs that are designed to achieve a specific level of treatment (i.e., performance standards) as set forth in Chapter 62-40, Florida Administrative Code (F.A.C.).

The rule requires Water Management Districts (WMDs) to establish stormwater pollutant load reduction goals (PLRGs) and adopt them as part of a SWIM plan, other watershed plan, or rule. Stormwater PLRGs are a major component of the load allocation part of a TMDL. To date, stormwater PLRGs have been established for Tampa Bay, Lake Thonotosassa, Winter Haven Chain of Lakes, the Everglades, Lake Okeechobee, and Lake Apopka. No PLRG has been developed for Alachua Sink at the time this study was conducted.

In 1987, the U.S. Congress established section 402(p) as part of the Federal Clean Water Act Reauthorization. This section of the law amended the scope of the federal NPDES to designate certain stormwater discharges as “point sources” of pollution. These stormwater discharges include certain discharges that are associated with industrial activities designated by specific Standard Industrial Classification (SIC) codes, construction sites disturbing five or more acres of land, and master drainage systems of local governments with a population above 100,000 [which are better known as “municipal separate storm sewer systems” (MS4s)]. However, because the master drainage systems of most local governments in Florida are interconnected, EPA has implemented Phase 1 of the MS4 permitting program on a county-wide basis, which brings in all cities (incorporated areas), Chapter 298 urban water control districts, and the DOT (Department of Transportation) throughout the 15 counties meeting the population criteria.

An important difference between the federal and the state stormwater permitting programs is that the federal program covers both new and existing discharges while the state program focuses on new discharges. Additionally, Phase 2 of the NPDES stormwater permitting program will expand the need for these permits to construction sites between one and five acres, and to local governments with as few as 10,000 people. These revised rules require that these additional activities obtain permits by 2003. While these urban stormwater discharges are now technically referred to as “point sources” for the purpose of regulation, they are still diffuse sources of pollution that can not be easily collected and treated by a central treatment facility similar to other point sources of pollution, such as domestic and industrial wastewater discharges. The DEP recently accepted delegation from EPA for the stormwater part of the NPDES program. It should be noted that most MS4 permits issued in Florida include a re-opener clause that allows permit revisions to implement TMDLs once they are formally adopted by rule.